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# FOREIGN TECHNOLOGY DIVISION

## THE EXPERIENCE OF SOVIET MEDICINE DURING THE GREAT PATRIOTIC WAR. 1941-1945

by

Ye.I. Smirnov

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# EDITED TRANSLATION

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THE EXPERIENCE OF SOVIET MEDICINE DURING THE GREAT PATRIOTIC WAR. 1941-1945

By: Ye.I. Smirnov

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## U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

| Block | Italic | Transliteration | Block | Italic | Transliteration |
|---|---|---|---|---|---|
| А а | *А а* | A, a | Р р | *Р р* | R, r |
| Б б | *Б б* | B, b | С с | *С с* | S, s |
| В в | *В в* | V, v | Т т | *Т т* | T, t |
| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

## RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

| Russian | English | Russian | English | Russian | English |
|---|---|---|---|---|---|
| sin | sin | sh | sinh | arc sh | $\sinh^{-1}$ |
| cos | cos | ch | cosh | arc ch | $\cosh^{-1}$ |
| tg | tan | th | tanh | arc th | $\tanh^{-1}$ |
| ctg | cot | cth | coth | arc cth | $\coth^{-1}$ |
| sec | sec | sch | sech | arc sch | $\operatorname{sech}^{-1}$ |
| cosec | csc | csch | csch | arc csch | $\operatorname{csch}^{-1}$ |

| Russian | English |
|---|---|
| rot | curl |
| lg | log |

**GRAPHICS DISCLAIMER**

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# SECTION FIFTEEN

# FIREARMS WOUNDS AND INJURIES OF THE PERIPHERAL NERVES

GENERAL SECTION

## CHAPTER I

## A BRIEF HISTORICAL OVERVIEW OF THE METHODS OF TREATING FIREARMS WOUNDS OF THE PERIPHERAL NERVES

Professor S. S. Bryusova

"Whoever has dealt with injuries to nerve trunks knows how slowly and poorly their function is restored and what suffering can be associated with the formation of the scar, how often the wounded remain cripples and martyrs for their entire life from the damage inflicted to a single nerve trunk". These words of Pirogov, written by him in 1864, briefly characterize all the clinical severity of the suffering and helplessness of treatment in those days.

Pirogov already knew that the fusion of a severed nerve takes place with the aid of intermediate tissue in which "not only new nerve fibers are formed, but, it seems, the very axial cylinders themselves". He knew that neuromas develop on the ends of a severed nerve, which may become the source of great pain which does not always disappear with excision. He received information on the first efforts at applying a nerve suture, "whose application in operative and military practice was extremely important". All this, however, was insufficient for the practical development of surgical methods for treating firearms wounds of the peripheral nerves under the conditions prevailing at that time.

In the years of the Sevastopol campaign and the Caucasus expedition, nerve injuries were considered rare, which depended to a greater degree on the firearm inflicting the wound. N. I. Pirogov presents from his practice only a few cases of severance of the nerve trunk. "Contusions" and "concussions" of the nerve in firearm wounds to the extremities in those days were also rarely observed. Nerve damage attracted attention not so much due to the loss of movement and sensitivity as due to the accompanying pain. "It was much more common to

see hypersthesia due to firearms projectile damage to the extremities than it was to see paralysis"[1]. Among the reasons causing "local traumatic neuralgia and hypersthesia", primary attention was focused on foreign bodies "entering the nerve or lodged nearby", as well as on displaced bone fragments causing "pressure on the nerve" with their sharp ends. Setting of the fragments or removal of their sharp ends achieved the purpose of eliminating the pain, and exhausted the sum total of surgical intervention. In those cases when damage to the nerve occurred without any manifestation of irritation, no treatment was given. N. I. Pirogov indicates that in most cases after firearms wounds to the extremities, the nerve function was restored independent- /11
ly, although not fully. If the pains resulted from inflammatory or cicatrical processes, cold or heat, cantharides, and ointments with narcotic substances were used. After passage of the acute period, N. I. Pirogov recommended treatment at health resorts, application of local and general baths, and faradization -- a measure which has retained its importance to the present day.

Nelaton (Nelaton, 1863) and Laugier (Laugier, 1864), who were the first at that time to use primary and secondary wire suturing of the nerve, observed the restoration of function within several days. N. I. Pirogov reacted critically to these reports, doubting the possibility of a nerve healing by first intention and explaining the early restoration of function by the existence of anastomoses. However, he did immediately evaluate the important significance of the nerve suture. It is true, however, that much time passed before the nerve suture was accepted into practice and surgical treatment of nerves damaged by firearms wounds became generally accepted.

The old methods of treatment continued to prevail in field hospitals for yet a long time, although the principles of antiseptics

---

[1] N. I. Pirogov, Nachala obshchey voyenno-polevoy khirurgiyi, ("The Origins of General Military Field Surgery"), vol. 1, p. 279, 1865.

and aseptics were already beginning to penetrate into the surgical clinics and hospitals. N. V. Sklifosovskiy, who began using antisepsis in the clinic in the 80's, was unable to utilize it under wartime conditions during the Russo-Turkish War of 1877-1878. There is absolutely no mention of nerve damage in the military-medical records during the time of this war. There is also no information on later interventions on nerves in subsequent years. Thus, in the Moscow military hospital over a period of 10 years of application of the antiseptic method (1881-1891) in 1,620 operations performed, there is mention of only one operation performed on the nerve, when stretching was performed, used at that time for neuritis.

From the reports of surgeons in this country and abroad who participated in the 90's in various campaigns, it is evident how slowly the principles of antisepsis and asepsis were introduced into the practice of military field surgery, and how little attention was given to the treatment of damaged nerves. In 1894-1895 during the Japanese-Chinese war, only the antiseptic treatment of wounds was used in military field practice. Information on wounds to the nerves is absent. During the Anglo-Boer War (1898-1899), participants of the Russian Red Cross team sent to Africa, who were equipped with surgical instruments and apprised of the latest scientific knowledge, found unsanitary ward conditions and total surgical ignorance on the part of the Boer surgeons.

Beber, in his work on firearms injuries in the Anglo-Boer War, described 4 cases of nerve injuries. The official English report mentions 41 cases of such injuries, but there is no indication of any successful operative treatment. During the Chinese War, V. S. Galin, characterizing the activity of the Russian field hospitals, does not give any information on the treatment of damaged nerves. Nevertheless, by that time questions on the nerve suture, on plastic surgers on nerves, and even on the use of transplants were already being developed. The possibility of nerve regeneration after application of a suture not only had been proven experimentally, but also demonstrated on operated patients, although such operations

were still rare. I. K. Spizharnyy in 1894 collected in the world literature 192 cases of application of nerve sutures over a period of several decades. It is true that among these there were only 8 cases in which the injury was caused by firearms-inflicted wounds and there were several cases of nerve severance resulting from slash wounds inflicted by sabre. The overwhelming number of cases related to every- /15
day trauma. According to the compiled statistics of I. K. Spizharnyy it is evident that the primary suture was used in the nearest days after the injury, as well as the secondary -- applied several months later. Thus, for example, already in 1881 N. V. Sklifosovskiy obtained positive results after primary suturing of the median nerve which had been severed by glass. However, generally the results were quite varied. In any case, by the beginning of the XX century, operations on the peripheral nerves already comprised a specific chapter in surgery, many sections of which had already by this time reached their bloom.

During the Russo-Japanese War (1904-1905), attention is for the first time given to wounding of the peripheral nerves, and operative treatment is begun in rear-echelon hospitals. It must be considered that during the Russo-Japanese War there were significant changes in military tactics. Firearm-inflicted wounds were inflicted by more varied and more powerful weapons. Small calibre bullets which had become widespread, due to their great speed and force, caused more extensive and more severe wounds. Shrapnel and shell fragment wounds became more frequent. All this led to the increased frequency of wounds to the peripheral nerves. On the other hand, the achievements of conservative treatment made it possible in some cases to save extremities which had previously been subject to amputation. This also increased the number of casualties having nerve damage. There are no reliable statistical data on wounds to peripheral nerves during the time of the Russo-Japanese War. We may obtain some idea of these wounds from the data of L. S. Minor, who witnessed 26,900 wounded and sick passing through the Moscow evacuation commission assembly point. He established damage to the peripheral nerves in less than 1.0% of the cases, but did not separate the statistics on wounds inflicted by firearms. If we turn to the other, very few

works which reflect the personal experience of surgeons, the very small number of patients with firearms-inflicted wounds of the peripheral nerves subject to operation becomes very apparent. R. Kh. Vanakh had the most extensive material at his disposal (hospital in Irkutsk). In 434 cases of wounds to the extremities, he observed 30 cases of nerve injury. Of these, he performed operations in 22 cases. Other Russian surgeons had singular observations of nerve damage (V. A. Oppel' -- 7 operated wounded, A. F. Voynich-Syanozhenskiy -- 6, S. F. Deryuzhinskiy -- 10 wounded, of these 4 were operated). The foreign literature also does not reflect greater material. The German surgeon Genle, working in Tokyo, reported on 36 cases of wounded with nerve damage, of which 20 were operated. Of course, based on these reports it is impossible to form an opinion on the frequency of nerve trunk damage. They may only characterize the first steps in operative treatment of nerve injuries under wartime conditions.

The surgeons working in hospitals at that time usually did not use the aid of a neuropathologist and were unable to use various test methods for their diagnosis. Nerve damage was recognized by motor dysfunctions and sensation disorders. The absence of improvement for a period of 1-2 months served as an indication for operative intervention. Various operations were tried. Neurolysis was used in the case of pressure on nerves exerted by scars or bone clavus. V. A. Oppel' gave neurolysis a positive evaluation, but R. Kh. Vanakh was more restrained in his reaction, since in some cases he observed insufficient or only temporary improvement. With severance of the nerve or with gross cicatrical degeneration, the scar tissue and the nerve ends had to be excised. The nerve suture was also used, which /16 in many cases gave restoration of the conduction. With large defects, plasty was used, cutting the grafts out of the peripheral, central, or both ends of the nerve and forming a bridge out of them. R. Kh. Vanakh used this methodology 8 times, and in 5 cases there was significant improvement in movement in several months. V. A. Oppel' felt that nerve resection with subsequent plasty may be allowed only

in the form of an exception. By comparison, foreign surgeons used the application of anastomosis, i.e., suturing the damaged nerve into the split of a neighboring healthy nerve, much more frequently (Genle). However, Russian surgeons (R. Kh. Vanakh and V. A. Oppel') viewed this method with distrust. A. F. Voynich-Syanozhenskiy considered all the contemporary methods of neuroplasty in his time insufficiently perfected. However, all such opinions were not confirmed by practical experience.

With interventions on the nerve trunk, its isolation was considered necessary. In Japan, Hashimoto used a formaline treated calf artery as a casing. Russian surgeons strived toward more physiological methods and used neighboring fascia and muscles (V. A. Oppel'), or in general did not feel that it was necessary to surround the nerve with any kind of tissue (S. F. Deryuzhinskiy). Of the methods of conservative treatment, they used electrization, massage, blue light, and baths.

Thus, during the Russo-Japanese War, surgical treatment of firearms wounds of the nerves was used for the first time in hospitals, where neurolysis, nerve suture, and plasty operations were tested. However, the number of interventions performed was too insignificant. The experience obtained during the Russo-Japanese War was clearly insufficient, which gave P. I. D'yakonov the right to negatively evaluate it at the XVII Congress of Surgeons.

By the beginning of World War I, the study of the nerve regeneration process and the technology of nerve operations had somewhat progressed. It had been firmly established that the healing of a nerve wound is a complex process in which it is impossible to speak of first intension. Nerve regeneration had been studied experimentally with various suture technology. The effect of local infection on the outcome of the restoration had been determined (P. M. Krasin, 1907, 1911). The role of the peripheral cut in regeneration became clear, which gave anatomic-physiological sub-

stantiation for establishing an optimal time for intervention (I. K. Spizharnyy). The necessity of using sparing technology and special instruments became generally known, but each surgeon could only individually begin mastering the questions associated with the problem of treating damaged nerves and with the technology of operative intervention.

During World War I, the number of wounded with peripheral nerve damage was already expressed in the thousands, and the problems of treating these wounds took on great importance. According to Levandovskiy (Lewandowsky), in the German army in 1914-1915 there were 10,000 cases of nerve trunk wounds, which comprised 1.5% of the overall number of wounds. During 1915, there were 150 wounded with peripheral nerve injuries under the observation of A. I. Geymanovich and A. A. Skornyakov. P. I. Stradyn', generalizing the experience of the war years, collected 817 such cases.

Despite the increased need for active surgical treatment, the opinions on its role were most conflicting -- ranging from full rejection of the expediency of intervention [Benisti (Benisti)] to requirements for operation without exceptions if there was no improvement within 2-3 weeks [Gosse (Gosset)]. The operative techniques used were extremely variegated, particularly in the initial period of the war. /17

It is characteristic that in certain rear field hospitals, surgeons began working in contact with neuropathologists. Efforts were also made to concentrate wounded with peripheral nerve injuries in special field hospitals (A. I. Geymanovich and A. A. Skornyakov). A more detailed study by neuropathologists of the clinical course of sustained wounds made it possible to present the question of "pathologo-anatomical individuality" of the separate nerves and to isolate a number of symptoms characteristic for various types of injuries to nerves and their regeneration. The need was established for a systematic study of sensibility and movements, and there was

more frequent insistence by individual authors for the study of electroexcitability of nerves prior to operation. Testing nerve conductivity was begun using sterile electrodes, in individual cases during the operation. However, the basic criterion for operative intervention still remained the prolonged absence of functional restoration.

Not only was the uncertainty in the character of the injury a reason preventing early intervention, but also the fear of infection. Therefore, the time for the operation was determined primarily by the time elapsed after healing of the wound. In most cases, it was recommended to wait a period of three months after healing to perform the operation. This often prolonged the waiting period up to 6-12 months from the moment of sustaining the wound. Early operations were performed as an exception in cases of wounds accompanied by pain (V. L. Bogolyubov et al.).

In the course of the war, operative discoveries were studied and repeatedly described. Gradually, with the accumulation of surgical experience, it became more feasible to more fully determine the character of the injury by the macroscopic picture on the operating table and to select the appropriate type of intervention.

The principles of techniques for operating on nerves in respect to careful performance of manipulations, thoroughness of hemostasis, use of appropriate instruments, corresponded generally to modern requirements. However, the types of operations, their selection with various forms of injuries and individual details of operative technique were marked by their wide variation. In preserving the anatomical continuity of the nerve trunk, most surgeons limited themselves to neurolysis, completing the excision of the scar tissue with isolation of the nerve. Surgeons excelled in the invention of methods whose purpose was to guard the nerve against repeated involvement in the scars. The traumatized nerve section was placed in calf's artery reinforced in formaline, wrapped in a piece of fat, a dissected vein (P. A. Kupriyanov, P. M. Krasin), or surface fascia taken from the abdomen (F. I. Bulatnikov), etc. With cicatrical

degeneration of the nerve, it was recommended that incisions be made on it and the trunk split longitudinally, with both halves later being sutured, or it was recommended that an oval piece be excised from the thickness so as to cause "insult necessary for regeneration of the nerve" (A. D. Pavlovskiy). In the application of a nerve suture, various methods were proposed for purposes of increasing the contact surface: aside from a slanted cut, it was recommended that the nerve end be given the form of a wedge or that one conical cut end be inserted into the corresponding gap in the other end. If it was impossible to bring the nerve ends together, various efforts at performing plasty were made: 1) catgut or silk threads were stretched between the ends; in order to replace such a suture at a distance with autogenic material, the ends of flat wide fascia from the femur and even the periosteum were used to join the ends (L. M. Krasin); 2) various types of grafts were cut one of the ends of the severed nerve for elongation; 3) pieces of cutaneous nerves were sutured into the defect (L. M. Pussep). It was also believed that a section of vein could be inserved instead of the nerve, thereby creating a tube for nerve fibers to grow within. Anastomoses "end to side" and "side to side" were applied between the damaged and healthy nerve. Healthy motor nerve branches were sutured together with a piece of muscle into a paralyzed muscle in the anticipation that the nerve fibrillae would spread, etc. The accumulated experience gradually made it possible to discard the least physiological methods. Unfortunately, an evaluation of the results of these various interventions was hindered due to the short-term post-operative observation of the wounded in field hospitals, as well as the lack of systematic consideration of distant results.

Thus, in the course of World War I, operative treatment of firearms-inflicted nerve wounds became widespread, and the experience of authors in this country and abroad made it possible to clarify numerous questions in recognizing and treating firearms injuries to peripheral nerves, and significantly altered the old presuppositions. No one considered nerve operations to be "useless adventurism" any longer. Most surgeons were inclined toward a moderate waiting period (2-4 months). The control of electroexcitability of nerves not only

before the operation, but also on the operating table was introduced into practice. Considering the harm of unsubstantiated radicalism, many surgeons switched to the application of more conservative methods of operation. Some surgeons rejected the preliminary desanguination of the extremity and operating under a tourniquet. For purposes of ensuring better asepsis, part of the surgeons recommended a "dry" operation (V. I. Razumovskiy), while others, in the battle against drying of the wounds, started using moist towels and irrigation with physiological solution (N. N. Burdenko). With severance of the nerve, preference was given to end-to-end suturing, rejecting tubulization and preferring to place the sutured nerve into an undamaged muscle bed. Studies seeking new methods of treatment to combat persistent pain were begun. V. I. Razumovskiy began using endoneural injection of alcohol, thereby laying the foundation for the method of blocking, which subsequently took on a definite place among neurosurgical interventions. Freezing of the nerve with chlorethyl, periarterial sympathectomy (V. N. Shamov) or intra-truck resection of the sensory conductors were all tested. However, pain therapy remained in a "rather sad state" (M. F. Dobrokhotov), and the first efforts at influencing the sympathetic system (desympathization of the arteries according to Lerish) more often than not met with failure. Many authors felt that it was preferable to conduct long-term post-operative treatment with the application of physiotherapy methods, but under the conditions of field hospitals in czarist times the methodical finalization of treatment remained impossible.

After the end of World War I, the question of treating nerve damage entered a further phase of development. A large contingent of invalids with injuries to the peripheral nerves had the opportunity after the October Socialist Revolution to continue treatment in special institutions, first organized in Leningrad and then in other large centers.

The school of V. N. Shevkunenko presented the problem of the changability of the peripheral nerves and established the regularity of innervation variants, thereby ensuring a more correct interpretation of atypical clinical pictures. Anatomical studies clarified /19

the possibility of double innervation, the frequent transitions of fibers from one nerve trunk to another, overlapping in contiguous zones of innervation, etc. The school of I. P. Pavlov worked in developing the problems of the physiology of the vegetative nerve system and the problem of pain. Clinical materials were used by A. L. Polenov to study trophic disorders and pain syndromes after injury to the peripheral nerves. [Polenov] presented the theory of reflectory pathogenesis of residual disorders, tested their varied interventions on the somatic and sympathetic system for treatment purposes, and proved the favorable effect of operations which disintegrate the nerve reflex arch and act on the vasomotor system.

A. G. Molotkov developed his conception on the trophic nerves and on the therapeutic effect of intersection certain cutaneous branches. Operations on periarterial sympathectomy and intervention in the sympathetic ganglia were subjected to widespread verification.

The works of Soviet scientists studying the processes of nerve regeneration are deserving of particular attention. The regularity of the neuroma arising on the central and the glioma-fibroschwanoma arising on the peripheral end of an intersected nerve (L. I. Smirnov) was thoroughly studied, and the significance of processes developing in the peripheral segment for regeneration of the nerve fibers was established [B. S. Doynikov, Yung (Joung) et al.]. Finally, all the stages of degeneration and regeneration of nerve elements were observed in detail.

Later, with the aid of the method of vital staining (B. I. Lavrent'yev), the participation of the vessels in the regeneration process was clarified. These theoretical data substantiated an entire series of practical conclusions on the times and techniques of nerve suture application.

Soviet physiologists used the most modern methods of electrophysiology in the study of the regeneration process. P. K. Anokhin, studying the conduction of stimuli through the nerve scar, presented

the question on the meaning of the "generalization phenomenon". Due to the absence of myelin and special physio-chemical conditions in a certain stage of development of the nerve scar, center-directed and centrifugal impulses are distributed laterally in the scar and generalized. Excess growth of axons ensures their multilateral connection. In this stage, the impulse goes from the periphery to the central segment in a disorganized manner both in the number of stimulated central axons and in the character of the stimulated fibers. However, not every fiber accepts the impulse in the same intensity and frequency. Then the axons are myelinized and isolated from the currents. Gradually the impulses pave a passage over the scar along certain fibers and adequate relations are worked out between the peripheral and central apparata. This thinking confirms the significance of the scar in the regeneration process, explains the connection between the periphery and the center, and does not contradict the concept of clinical sequence of indicators of conductivity restoration.

Electrophysiological studies have shown that nerve fibers of various thickness differ not only by their varied speed of conducting impulses, but they also have different vulnerability, a different capacity for resistance to the effects of cold and mechanical pressure, which is important in understanding the clinical picture of the nerve block after a trauma and the by-stage restoration of functions after neurolysis.

In connection with the development of theoretical problems, a /20
more detailed diagnosis has become possible and the earlier and more precise solution to problems concerning the character of the injury, the extent and stability of the conductivity break has been facilitated, as has been the solution to problems concerning indications for intervention and selection of the operative method. A series of electrophysiological methods was introduced into clinical practice: chronaximetry, the study of biocurrents (V. S. Rusinov, S. A. Chugunov), electrothermometry; the study of perspiration became

widespread according to the method of V. L. Minor, as well as the study of the vasomotor function. Much has become known concerning the individual specifics of nerve endings and the uniqueness of symptoms present for each nerve.

Noticeable shifts also took place in operative techniques. The old approach methods described in all the textbooks for half a century were subjected to criticism. G. A. Rikhter steadfastly proposed extra-projection approaches, pointing out the harm in cutaneous and fascial incisions accompanied with nerve projection. New approach methods were worked out for areas of peripheral nerves with difficult accessibility. A more sparing technique was perfected: for example, regeneration of the nerve ends with a razor blade, drying the wound by suctioning off blood, stopping hemorrhaging by electrocoagulation (B. G. Yegorov). The connection of the ends with adhesive plasma and the isolation of the nerve suture with hemostole. A particularly great number of efforts was made in respect to plastic replacement of large nerve defects. Nazhott (Nageotte) in 1918 proposed the implantation of nerves from a calf indurated in alcohol. After this, the most varies types of transplants were tested for grafting: spinal marrow from a cat or rabbit indurated in formaline, the nerves and veins of animals frozen at ultra-low temperatures. Most of the methods were experimentally and clinically tested by Soviet scientists, who proposed certain modifications (formaline treated nerve according to A. P. Anokhina, alcohol-glycerin preparations of A. A. Shabadash).

From the time of the first world war, methods of homotransplantation were also being developed. As early as 1919, the storage of nerves on ice, in alcohol, and in vaseline oil was experimentally tested. Most often, autoplasty was proposed with transplant of the cutaneous branch. As early as 1917, L. M. Pussep attempted to suture several pieces of cutaneous nerve which formed a "cable" of corresponding diameter to a thick stem, and obtained restoration of conductivity. It was recommended that the transplanted branch be prepared in time by cross-cutting. Z. I. Geymanovich studied the

replacement of defects using a piece of indurated serum prepared from the blood of the patient. Almost all the proposed methods of plasty in the experiments and in individual clinical cases led to the regeneration of fibers and to some restoration of conductivity. However, the evaluation of the practical significance of all these methods was for the most part sustained.

Much attention was given by N. N. Burdenko to methods of restoring the nerve with defects which were inaccessible to the nerve suture. In his original experiments, where the end of a severed nerve encased in a cutaneous jacket was subjected to long-term gradual extension by a suspended weight, N. N. Burdenko proved the possibility of significantly lengthening the nerve trunk without gross traumatization. However, this method was not sufficiently developed for application in clinical practice.

Throughout the course of the long period of peacetime, extensive material was studied, which showed the effectiveness of operative treatment. However, such variation prevailed in the times of observation and particularly in the criteria for evaluation that the possibility of result comparison was excluded. Observations of Soviet neurosurgeons showed that wounds inflicted by firearms in wartime give a lower percentage of positive results than wounds sustained during peacetime, but nevertheless in the former group, significant restoration of the motor function was noted in 53.0% percent of the cases (A. L. Polenov). It was established that the results are affected by the character of the injury, which nerve is damaged and at which level, the type of operation, the age of the patient, and other factors.

The experience of combat near Lake Khasan and at Khalkhin-Gol again attracted attention to military field wounds to the peripheral nerves. The question arose of organizing specialized neurosurgical aid, as well as of the necessity of familiarizing the broad circle of physicians with the basic devices for the treatment of neurotrauma. The hope of creating specialized aid was realized during the war with the White Finns. The work experience of the neurosurgical

section in the evacuation hospital unquestionably yielded positive results. The special directionality in the work of the neuropathologists made it possible to recognize more specifically the degrees and character of injury to the nerve trunk, and to give a more correct evaluation of cases at various times, beginning from the first day. Front line conditions during the Finnish campaign did not allow for testing of the primary suture. However, a number of surgeons began calling for a shortening of the waiting period and for an early second operation.

The war with the White Finns prompted N. N. Burdenko to create a special restorative surgery section at the Central Neurosurgical Institute for wounded with nerve damage. Here the wounded were studied according to the complex principle by various specialists, the latest diagnostic methods were tested, and a new methodology for operations was developed (in particular with large defects of the nerve trunks and with irremovable pains). Here, formalin treated nerve transplants were used for the first time on humans (according to the method of P. K. Anokhin) and here N. N. Burdenko in cases of causaglia and painful neuromas, along with operations on the sympathetic ganglia, used treatment of the traumatized nerve area under control of a magnifying glass for purposes of combatting microaneurysms and microneuromas.

Materials from the war with the White Finns made it possible to conduct a series of observations of a theoretical character. Thus, the studies of B. A. Favorskiy are interesting, who established in casualties killed as a result of severe firearm-inflicted wounds of the extremities changes in the segmental centers of the spinal cord. These data confirmed the experimental works (by the same author and by V. V. Semenova-Tyanshanskaya), which showed that an isolated trauma of the nerve trunk leads to histological changes of the "primary irritation" type in the cells of the anterior horns and in the intervertebral ganglia at the corresponding level.

Although by the beginning of the Great Patriotic War (World War II), Soviet neurosurgery already had at its disposal certain devices

in respect to the treatment of firearms-inflicted wounds of the peripheral nerves, nevertheless the experience of the war with the White Finns again raised the questions which had worried surgeons a quarter century earlier. Again the inadequacy of knowledge in regard to the pathogenesis and mechanism of action of numerous disorders associated with nerve trauma became apparent. The question of times of intervention became acute, particularly in connection with new capabilities of combatting infection (the introduction of sulfamides into practice). Methods of operating on nerves were reviewed /22
and checked, as well as their modifications under complex anatomical conditions and their effectiveness. It is notable that at the Plenum of the Scientific Medical Soviet in 1942, N. N. Burdenko indicated the need to review almost all the accepted devices, "beginning with morphology, vascularization, physiology, pathological morphology and physiology of regeneration", as well as questions "on diagnostics, on indications and counterindications for intervention and operative methods".

However, the anatomo-localistic devices which prevailed among physiologists and clinical practitioners somewhat hindered the development of numerous questions associated with the trauma of the peripheral nerves. The introduction of the ideas of I. P. Pavlov into neurosurgery is capable of solving many of these questions and opening prospects for the further, more fruitful development of the problem of treating trauma of the peripheral nerves.

In the years of the Great Patriotic War, all the details of the complex problem of treating firearm-inflicted injuries to the peripheral nerves were subject to review. Soviet scientists of the most varied specialties, including specialists in anatomy, histology, and physiology, as well as a wide range of doctors -- surgeons, neurosurgeons, neuropathologists, roentgenologists, orthopedists, psychopathologists, and others were included in the development of theoretical and practical questions. Each of these multilateral studies to a certain degree left its impression on the collective experience which is reflected in this "Work".

## CHAPTER II

## GENERAL QUESTIONS OF FIREARMS INFLICTED WOUNDS TO THE PERIPHERAL NERVES

### A classification of firearms wounds to the peripheral nerves

Professor B. V. Yegorov, Member-correspondent, AMN SSSR

A rather complex and as yet far from completely settled question /23
in the entire problem of wounds to the peripheral nerves is the classification of this type of injury. Bringing the various forms of injuries to the peripheral nerves into a single structured, sequential system, giving an objective picture of the morphological changes characterizing the clinical manifestations of the injury, determining the functional-dynamic condition which is a result of the pathological process and which is reflected in the disrupted function of the damaged nerve -- all this comprises an exceptionally difficult task.

The multilateral experience of the Great Patriotic War in the area of firearms injuries to the peripheral nerves allows us to make certain anatomical, clinical and physiological generalizations which characterize the development of the wound process, and to attempt to present a rational classification of combat nerve injuries.

The classification is structured on the principle of uniting the basic and characteristic specifics of injuries to the peripheral nerves and distributing them according to their most important indicators. The purpose of the classification is to: 1) facilitate the recognition of firearms inflicted injuries to the peripheral nerves, determine the tactics of the surgeon, clarify the evacuational description and substantiate the prediction of the further course; 2) facilitate the organization of rational computation of these injuries; 3) improve the possibility of scientific study of combat injuries to the peripheral nerves.

The classification must be based on the unification of anatomical and clinical data and on the pathophysiological mechanisms of injuries to the peripheral nerves, and must encompass the different stages of the traumatic process with their most characteristic specifics.

However, even in constructing the classification on such a wide base, it must be stressed that many cases of injuries to the peripheral nerves cannot be relegated to one or another heading of the classification scheme if we do not consider the influence of compensatory mechanisms of the central nervous system. The latter condition a number of variations which require the isolation of a series of cases of peripheral trauma from the general typal determination. This also corresponds to the correct indication by P. K. Anokhin that "nerve trauma has ceased being merely a peripheral episode, and has come to /26 be viewed as a particular expression of the inevitable trauma to the central nervous system".

Therefore it is always necessary to keep in mind that the type of injury, no matter how uniform it may seem to be at first glance, in individual cases has unique clinico-anatomical (structural-morphological) and physiological (functional-dynamic) differences at various stages and at various periods in the course of the pathological process, starting from the moment of injury.

Firearms inflicted injuries to the peripheral nerves are divided into three basic groups (see classification): complete anatomical severance, partial anatomical severance, and intra-trunk changes without damage to the epineurium.

Characteristic for complete anatomical severance in the acute period, regardless of the degree of divergence of the nerve endings is: hemorrhagic permeation of its segments; accumulation of erythrocytes between the nerve fiber fascicles; appearance of droplet and globular products of the disintegration of myelin and the axial cylinders, as well as the degeneration and disintegration of the Schwann cells and elements of connective tissue. Somewhat later the Schwann cells begin to perform the function of granular globes, and then proliferate intensively.

A CLASSIFICATION OF FIREARMS INFLICTED WOUNDS TO THE PERIPHERAL NERVES[1]

| Anatomical (structural-morphological) type | Clinical type | Physiological (functional-dynamic) type |
|---|---|---|
| Complete anatomical severance | | |
| 1. Gross divergence of the ends of the severed nerve: | Loss of the motor, sensory, vasomotor, secretory, and trophic functions | Complete absence of nerve excitability.<br>Loss of galvanic and faradic excitability<br>Flaccid "worm-like" character of weak muscular contractions |
| a) acute period: hemorrhagic permeation of the segments of damaged nerve | Severity and irreversability of functional disruptions is a characteristic trait of the developing clinical syndromes | |
| b) residual period: formation of neuroma and fibroschwanoma of the peripheral segment | | |
| 2. Without gross divergence of the severed nerve ends: | The same clinical syndromes, but after a certain time -- spontaneous partial restoration of functions (later period) | The compensatory mechanisms often have a great effect on the functional capability of the denervated organ. This phenomenon in later periods may lead to re-structuring of the functions. |
| a) acute period -- massive hemorrhaging | | |
| b) residual period -- lateral neuroma, cicatrical overlaps between breaks | | |

Partial anatomical severance

| | | |
|---|---|---|
| 3. The anatomical relationship of severed nerve trunk ends is unchanged:<br>a) acute period has its own characteristic features<br>b) residual period has its own characteristic features | Loss of functions, often all types, as in complete severance. This latter phenomenon develops as a result of partial severance and inhibition of conductivity not only in the local conductors, but also in the segmental centers (reflex paralysis). | Diaschisis. Partial reaction of muscular degeneration. Normal or reduced contractions; in the latter case -- elevation of excitability threshold. In a number of cases the functional condition of the nerve trunk remains stable. |

Intra-trunk changes with firearms wounds to the peripheral nerves without damage to the epineurius

| | | |
|---|---|---|
| 4. a) Acute period: gross and mild damage to the peripheral nerves, depending on the intra-trunk processes occurring as a result of injury to the nerve by fine particles of dust, hair, hemorrhages breaks introduced into it. | In the early period -- functionally severe loss of all forms of innervation; in time the character, intensity and volume of clinical expression changes. By the later period there is already marked a more or less expressed volume of disruption and corresponding loss of functions in the zones of innervation. | Diaschisis. Often total disruption of nerve excitability at the beginning of the acute period. Then there is an illumination in the volume of nerve conductivity due to resolution of hemorrhages and liquidation of inflammatory reactions. Subsequently there is often again observed a limitation in nerve conductivity due to the development of endoneural scars in the area of previous hemorrhaging. |
| b) Later period: inflammatory changes merge and, finally, there is organization of endoneural fusions. | The intensity of limitation in nerve function in residual states with consideration of possible replacements is often quite varied. In the later period of illness, the organization of endoneural fusions may again often lead to reduction in the conductivity of the nerve trunk. | |

[1] Only the basic traits of each type of injury are presented in this scheme; for details, see text.

Changes in the peripheral segment affect the motor end patches /26 and the sensory endings.

Residual conditions with complete anatomical severance of the nerve depend on the degree of divergence of the nerve segments, on the massiveness of the induced trauma, and on the wound healing process.

With gross divergence of the nerve ends, residual conditions are characterized by the formation of a central neuroma and fibroschwanosis of the peripheral segment, without their cicatrical unification. A lymphocytic reaction is observed in both segments of the nerve, and is more clearly expressed with increased extent and gross disintegration of the nerve.

With suppuration of the wound, a leukocytic reaction is observed, with the presence of foreign bodies there is an inflammatory reaction with appearance of gigantic multinuclear cells. Granulation and cicatrical tissue develops.

Residual conditions with complete anatomical severance of the nerve without gross displacement are characterized by cicatrical unification of the nerve ends. With a favorable course of regeneration and corresponding structure of the scar band, its neurotization takes place and nerve fibers sprout in the peripheral segments.

Functional-dynamic changes with total anatomical severance of the nerve trunk consist of the following: 1) complete absence of nerve excitability (2-3 weeks after the occurrence of the trauma the nerve is degenerated); 2) loss of faradic excitability (according to the data of Vvedenskiy-Ukhtomskiy, the lability of the nerve tissues to currents of low and high frequency is absent); 3) flaccid, "worm-like) character of muscular contractions (the muscle fiber is degenerated, the passage of the stimulas along the degenerated fiber is slowed); 4) compensatory mechanisms often have a great influence on the functional capacity of the denervated organ. This phenomenon in later periods may leads to re-structuring of functions.

In distal regions of the extremities, particularly in the upper, the system of overlapping nerve trunks is widely developed (median and ulnar nerve). When, with injury to one of the trunks, its functions are partially replaced by the others, the muscle synergists with /27 normal or partially disrupted innervation also replace part of the lost functions of the denervated organ. The central nervous system also plays a great role in the re-structuring of functions, which was clearly proven by the experiments of P. K. Anokhin et al.

Clinically complete anatomical severance is characterized by a stable loss of functions -- motor, sensory, and secretory. Trophic phenomena are sharply expressed and have an irreversible character.

The indications of partial severance of the peripheral nerve in the acute period have in principle no distinctions from those with complete anatomical severance.

Residual conditions with partial nerve severance are associated with the extent of the traumatic injury and represent a complex combination of pathological processes inherent on the one hand in complete nerve severance (neuroma formation) with the accompanying complications (introduction of foreign bodies, hemorrhages, inflammation, connective tissue growth), or on the other hand characteristic for the trauma by changes in the nerve without damage to the epineurium.

Functional-dynamic disorders with partial severance of the peripheral nerve are characterized by the following manifestations:

1. Diaschisis. The reaction of muscular degeneration (part of the nerve fibers are degenerated, part regenerated, incomplete neurotization of the organ).

2. Normal or reduced contractions. In the latter case there is an elevation in the excitability threshold. With complete sprouting (regeneration) of the nerve, the electrophysiological indicators do not show sharp deviations, with partial -- the deviations are clearer. In a number of cases the functional condition of the nerve trunk is

quite stable. In cases when, along with good regeneration, there are processes of scar formation complicated by infection, presence of foreign bodies, etc., the functional condition of the nerve changes sharply and its conductivity is reduced, and sometimes completely lost.

3. The compensatory mechanisms are sharply expressed, often replacing the innervation of the severed nerve. With injury to a mixed nerve trunk, a large number of afferent and efferent fibers are destroyed which run in different directions within the trunk, intertwining with each other. Therefore, the compensatory mechanisms in this case do not regulate themselves as well after injury to a mixed nerve (there is no overlap).

Clinically partial anatomical severance of the nerve is distinguished by loss of functions, often partial, in the degree of the disruption as well as in its character.

Intra-trunk changes without damage to the epineurium in the acute period are characterized by a disintegration of the myeline and axial cylinders, degeneration and disintegration of the Schwann elements with subsequent transformation of part of them into granular globes. Hemarrhages and lymphocytic reactions are often observed.

Residual conditions are characterized by Schwann and connective-tissue growth, neuroma formation, inflammatory infiltrates often mixed with globules of blood pigment, and in cases of intervention of hair and dust particles into the nerve -- microgranulomas of foreign bodies.

Functional-dynamic disorders are manifested by the following indicators.

Diaschisis. The loss of all forms of innervation is at first severe, but in time changes its character and its intensity. The manifestations of diaschisis at first worsen the functional capacity of the nerve trunk. As the nerve recovers from the state of diaschisis, the functional condition of the nerve either normalizes or is somewhat reduced, depending on the organization of endoneural scars after /28

hemorrhaging in the nerve. During processes of scar formation, the conductivity in the nerve may fluctuate in one direction or the other in connection with the scar formation process.

The clinical symptoms of intra-trunk changes without damage to the epineurium are distinguished by their great polymorphism: they range from severe loss of function to weakly expressed ones, with frequent fluctuations in the course of the wound process, from growth in the restoration of the lost function to its diminuation.

For a more complete classification of firearms inflicted wounds to the peripheral nerves, it is necessary to note a series of characteristic specifics of injuries to the extremities. These specifics do not directly alter the basic traits of the classification groups presented above, but they do determine the character and severity of injury to the extremity and are reflected to one degree or another in the course of the wound process during injury to the peripheral nerves.

Depending on these distinguishing specifics, wounds to the extremities accompanied by peripheral nerve damage are divided:

a) by the character of injury -- into open and closed;

b) by the mechanism of injury and by the character of the wound channel -- into shearing, through, and blind wounds. The course of the wound channel, its depth and extent play a rather significant role in the diagnosis, treatment, and prognosis of the injury.

c) by depth of penetration of the wounding shell, the following types of firearms wounds to the peripheral nerves should be distinguished: 1) with damage to the soft tissue, 2) with damage to the soft tissue and bone, 3) with injury to the blood vessels, 4) with damage to the bones and the blood vessels.

Each of these injuries differs in the specifics of its course

and places a characteristic imprint on the clinical course of the illness. It requires a certain tactic in treatment and significantly influences the dynamics of the wound process of the injured nerve.

## On the mechanism of firearms inflicted wounds to the peripheral nerves

Distinguished scientist, Professor A. Yu. Sozon-Yaroshevich

It is necessary to speak of the mechanism of modern firearms injuries to the peripheral nerves particularly because in the Great Patriotic War the character and power of military armament changed radically in comparison with previous wars, and this could not help but be reflected in the character of injuries.

Two moments are of greatest significance in the question under examination: 1) the ballistic properties of the shells and 2) the resistance of the medium into which the shell penetrates, i.e., the physical properties of the nerves.

The weaponry of modern armies is so complex as compared with World War I, that today we must distinguish tens of types of shells, hand-held firearms, not to mention the various types of mines.

It is impossible to conduct a concrete study of the ballistic /29
properties of each of the modern wounding shells, and we will stress only the general regularities of their motion.

The live force of the bullet or fragment is the decisive factor. It is easy to see what great variation is caused by the values comprising the live force -- speed and mass. We must remember that the movement speed of the shell is affected by its form and the character of its surface. Fragments of mines and grenades give examples of the endless variation of these important values. In order to draw practical conclusions, the question must be studied experimentally and clinically.

A specific feature of modern warfare is the multiplicity of nerve injuries with the presence of several wound channels on the extremity. This is explained by the exception density of fire, when automatic weapons or shell fragments inflict multiple wounds to the extremity. Multiple injuries to nerves are observed in two forms: simultaneous injury to two or more nerves and multiple injury to the same nerve.

As concerns the physical properties of nerves as a medium determining shell resistance, in numerous experimental studies attention was given to three properties of nerve trunks: their great elasticity, and consequently high resistance to rupture, their variable degree of extension at the moment of injury, and their ability to be displaced in the surrounding fatty tissue and muscles at the moment of impact. It was noted that if the nerve is not extended, then due to its elasticity and capacity for stretching in the form of a loop, it may withstand breakage for a certain period of time. Also significant are details of the anatomical relationships which determine the uniqueness of wound circumstances: for example, the proximity of the radial nerve to the humerus creates a solid support during impact in the nerve and does not allow it to become displaced; or, for example, within the buttocks the sciatic nerve goes under the bone, and the conditions for its displacement under impact would be different than those in the central third of the thigh, where it is easily mobile and not extended. Attention was directed to the fact that in one position of articulations the nerve is tensed and the conditions for its injury would be different than in another articular position when the nerve is relaxed.

In short, the greater the degree of tension on the nerve, the less displacement it has at the moment of injury. The greater the live force of the shell and the more complex the shape and surface of the shell, the less chance there is of deflecting the nerve from the line of flight. On the other hand, the lesser the live force of the shell, the lesser the degree of nerve tension and the greater its mobility, the more conditions are present for its displacement. However, these factors of ballistics may have an effect only with slow

shell speeds. In most cases, however, the injury occurs instantaneously, and there is hardly time for displacement of the nerve or its extension. This was confirmed in experimental data obtained by B. D. Dobychin in studying wounds inflicted by various types of rifles. He established that the modern bullet, due to its high flight speed, causes injury to the nerve trunk without displacing the ends of the injured nerve.

Of great interest are paraneural injuries, already noted in World War I by certain authors and called nerve commotion. Their specific feature is the fact that the nerve remains macroscopically whole, but the patient develops paralysis. Certain authors have proposed that molecular changes in the nerve occur in such injuries. However, Borkhardt (Borchardt) demonstrated by means of early nerve revisions that hemorrhaging under the epineurium takes place in such /30
cases, sometimes at a considerable distance from the line of flight of the bullet. The experiments conducted by B. D. Dobychin on animals fully confirmed this and showed that the hemorrhaging may occur not immediately, but on the second day after the injury. Ye. M. Margorin in his anatomo-experimental and clinical work found that the source of the hemorrhaging is the extensive venous and arterial network located in the epineurium as well as in the perineurium and endoneurium. Hematomas cause periaxonal changes in the nerve fibers (disintegration of myelin with axon retention ) (B. S. Doynikov) and are resolved 2-3 months later, sometimes leaving traces of microscopic intratrunk cicatrices. Thus, if previously these injuries were explained by molecular processes, today they are explained by the ordinary impact action of the shell, which transmits its live force to the tissues neighboring the line of flight and is reflected primarily on the nerve vessels.

Tangential nerve injuries are close to these injuries. They differ from the preceding group in that, as a result of damage to the epineurium, tissue cracks appear in the injured nerve and infection has free access. This type of injury, as the preceding one, leads to the formation of scars around the nerve and serves as an indicator for neurolysis operation.

Through and blind nerve injuries comprise a special group. These injuries are caused by thin, sharp fragments which pierce the nerve like a needle.

B. D. Dobychin observed through (open) wounds in experiments with rifle bullets and explained them by the limited capacity of the nerve stretched between osteal points to be displaced at the moment of trauma. According to the materials of personal observations, aside from through wounds, blind nerve wounds were also observed: wounds of the brachial plaxis (fragment from a high-explosive shell), wound of the median nerve on the brachium (mine fragment) and wounds of the median nerve on the forearm (mine fragment). The fragments were removed during operations. In these cases one could hardly speak of the high speed of the shell or the impossibility of the median nerve moving out of the path of its movement. The mechanism of these wounds may most likely be explained by the particular form of the fragments which, like a needle or hook, are pierced into the dense nerve band which stands in their way.

The experience of the Great Patriotic War forces us to focus attention also on another type of foreign body, which is found quite frequently. These are small and minute metallic fragments which are invisible on X-rays, as well as threads and pieces of clothing. Being carriers of infection, they cause the formation of multiple granulomas, facilitate the development of massive scars and hinder axon growth.

Partial injuries to the nerve with severance not only of the epineurium, but also a part of the fascicles, do not present anything new as compared with the experience of past wars.

As we know, with complete severance, the ends of the nerve are often displaced and divergent for a certain, sometimes considerable, distance. Before neurosurgeons were inclined to explain this by the action of the shell. However, according to the experiments of B. D. Dobychin, the bullet does not cause significant displacement of the

ends of the severed nerve on a corpse, and only with damage to the bone do its fragments involve one or both ends of the damaged nerve. The ordinary displacements which are most often observed on the operating table are evidently explained by stretching of the nerve ends by scars and their subsequent shriveling. As concerns the diastase between the ends of the damaged nerve, which sometimes reaches considerable proportions, with the exception of cases where the damage was quite massive and accompanied by entrainment of tissue including the damaged nerve, and cases where part of the nerve perishes as a result of suppuration, most diastases should be attributed to the improper position of the extremity, in which the nerve is stretched and its ends separate away from one another.

During the Great Patriotic War, particular attention was focused on the combined injury of nerves and vessels, as well as nerves and bones.

From the standpoint of ballistics we must note that damage to a nerve lying next to a large vessel is difficult to imagine without damage to the latter, and that trauma to the nerve and vessel even in the slightest injuries is expressed primarily by a disruption in the vascularization of the nerves and innervation of the vessels.

The significance of combined injuries to the nerves from the viewpoint of ballistics consists of the fact that the fragments of the damaged bone, taking on the live force of the powerful shell, also become wounding shells and, splintering in every direction, they may damage the nerve even if the line of shell flight by-passes the nerve.

Even with low live force of the shell, the simple dislocation of a bone fragment at the moment of injury is capable of causing nerve damage if the nerve is located next to the break. The character of the latter injuries differs from wounds inflicted by a shell fragment in that they approach more closely the type of closed nerve damage, i.e., contusion, compression and crushing, although severance of the nerve is also possible. It is particularly with these injuries that the

properties of nerves which determine their resistance to pressure become apparent in their full measure: elasticity, degree of extension and displaceability in the surrounding tissue.

## General statistical data on firearms injuries to the peripheral nerves

"I am among the fervent advocates of rational statistics and believe that its application to military surgery constitutes undoubted progress". This is how the prominent leader in this country's medicine N. I. Pirogov evaluated and stressed the great significance of the statistical method of research in military-field surgery in his timeless work "The Origins of General Military Field Surgery" (1865). However, in subsequent scientific studies, the application of this method was extremely limited.

The lack of understanding and underestimation of the importance of medical statistics in military field surgery in all the preceding wars led to very serious defects in record keeping, in data collection, and in the methodology of processing this data. The report data of military-medic administrations did not include not only the individual types of injuries sustained, but also the firearms inflicted injuries of entire systems, as for example, damage to the peripheral nervous system. Because of this, the statistical data of all preceding wars were based only on the material of individual authors and could not fully reflect the frequency of firearms inflicted wounds to the peripheral nerves.

In the period of the Great Patriotic War, a system was developed for recording the organizational measures of treatment-evacuation provision with injuries to the peripheral nerves. This system not only considerably improved the quality of record keeping and improved the methods of processing and analyzing statistical material, but for the first time in the history of war it made possible the presentation /32 of actual materials which made it possible to generalize mass observations accumulated by medical science during the Great Patriotic War.

Table 1

The distribution of injuries individual peripheral nerves in relation to the entire group of given injuries

| Name of nerve | Percent of cases |
|---|---|
| Cranial | 0.15 |
| Cervical plexus | 0.04 |
| Brachial plexus | 5.84 |
| Radial | 15.57 |
| Median | 8.23 |
| Ulnar | 10.70 |
| Radial and median | 5.44 |
| Radial and ulnar | 1.94 |
| Ulnar and median | 8.22 |
| Ulnar, median and ulnar | 5.02 |
| Intercostal | 0.04 |
| Lumbar plexus | 0.23 |
| Femoral | 1.16 |
| Sciatic | 14.90 |
| Fibular | 9.42 |
| Tibial | 2.00 |
| Sciatic and femoral | 0.53 |
| Fibular and tibial | 9.86 |
| Combined injury to wounds of the upper and lower extremities | 0.71 |
| Total | 100.0 |

The literary data on the frequency of firearms inflicted wounds /33 to the peripheral nerves are quite varied. They are based on the material of specialized hospitals and have a primarily selective character. Despite the fact that these data are based on a comparatively large number of observations, they should be treated rather critically and carefully, since they do not show the general regularity, but only particular individual observations which reflect the experience of the author on material of primarily one stage.

Table 2

Frequency of injuries to the nerve trunks according to materials of personal observations

| Author | Distribution of injuries to individual nerves | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1-st place | 2-nd place | 3-rd place | 4-th place | 5-th place | 6-th place | 7-th place | 8 place |
| L.Ya. Brusilovskiy | Radial | Sciatic | Fibular | Ulnar | Median | 3 nerves | Brachial plexus | -- |
| S.P. Briksman | " | Ulnar | Sciatic | 2-3 nerves | " | Fibular | Tibial | Brachial plexus |
| A.M. Veger | " | " | 3 nerves | 2 " | 2 nerves | Median | Brachial plexus | -- |
| N.I. Grashchenkov | " | Median | Ulnar | 2-3 nerves | -- | -- | -- | -- |
| D.G. Gol'dberg | Ulnar | " | Radial | 2-3 " | -- | -- | -- | -- |
| A.A. Dikova | Radial | Sciatic | Ulnar | Sciatic | 2 nerves | Fibular | Tibial | Femoral |
| B.G. Yegorov | Sciatic | Median | Radial | Brachial plexus | Ulnar | Tibial | Fibular | -- |
| K.R. Erikh | Radial | Sciatic | Ulnar | 2-3 nerves | -- | -- | -- | -- |
| A.S. Zakharov | Median | Ulnar | Radial | Sciatic | Fibular | 2-3 nerves | Tibial | -- |
| N.M. Zelenskiy | Radial | 2-3 nerves | Brachial plexus | Ulnar | -- | -- | -- | -- |
| M.A. Topchibashev | " | 2-3 " | Median | " | -- | -- | -- | -- |
| D.G. Shefer | " | Ulnar | 2-3 nerves | Median | -- | -- | -- | -- |

According to the materials of the development of histories /33
of illness, it has been possible to establish the following distribution of wounds to the nerve trunks (table 1).

It follows from this table that first place in frequency of injury belongs to the radial nerve, second -- the sciatic, third -- the ulnar, fourth -- the tibial nerves, fifth -- the fibular nerve, sixth -- the median and combined injury to the median and ulnar nerve, seventh -- the brachial plexus, eighth -- injury to the radial and median nerve; ninth -- combined injury to the radial, median and ulnar nerve; tenth -- the tibial nerve, and last place -- the cervical plexus and the intercostal nerves.

On the question of frequency of injuries to the individual nerves, there is no unity in the literature. This is illustrated by table 2.

The conflicting data of most authors on the frequency of injuries to individual nerves depend in great degree on the different contingents of wounded under their observation. However, despite this fact, injuries to the radial nerve were observed much more frequently as compared with other nerve trunks, which is also reflected in the statistical material of World War I.

This relatively high frequency of injuries to the radial nerve is conditioned primarily by its topographo-anatomical location and its relation to the surrounding tissues. The radial nerve winds around the humerus along the outside anterior surface. This makes /34
it more vulnerable than the median and ulnar nerves, which are located along the internal surface of the brachium and parallel to it. Also, the radial nerve lies directly on the bone, and during injury of the latter may also sustain secondary injury. With closed fractures, the nerve is damaged directly by fragments or pinched between them. Sometimes the nerve was traumatized together with the bone as a result of the direct application of force. With injuries to the central and lower third of the brachium accompanied by affliction of the radial nerve, its motor branches to the tricipial muscle usually remained undamaged. With wounds in the area of the elbow joint, the

function of branches of the radial nerve running to the group of lateral and dorsal manual and digital extensors was damaged. It is necessary to distinguish primary paralysis and paresis of the radial nerve from secondary ones, which arise as a result of nerve compression by heavy swelling, hematoma, scar tissue, or a forming bone callous.

Damage to the femoral nerve was noted quite rarely, despite its considerable thickness, extensive zone of distribution and relative surface location. This may be explained by the fact that simultaneous injuries to the nerve and the femoral artery are usually accompanied by fatal hemorrhaging.

Due to the fact that, in injuries to the chest, particularly penetrating ones, the diagnosis of injuries to the intercostal nerves is difficult and sometimes completely impossible. Therefore they occupy last place among the injuries to the peripheral nerves. Also, when their injury is discovered, due to the severity and seriousness of the primary wound, the possibility of appropriate neurosurgical aid is excluded.

In the overwhelming number of cases (68.3%), wounds to the nerve trunks, according to the materials of development of illness history, were isolated. In the other cases, combined injuries of 2-3 nerve trunks were observed (fig. 1).

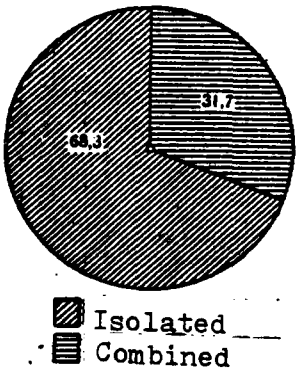



Fig. 1. The ratio of isolated to combined injuries involving two-three peripheral nerves.

Most often noted were combined injuries to the median nerve and other nerves of the upper extremity -- in 18.6% (the percentage was computed from the ratio of multiple nerve injuries to the injuries to all nerve trunks); of these, simultaneous injuries to the median and ulnar nerve were observed in 8.22%, of the median and ulnar -- in 5.44%, of the median, ulnar and radial -- in 5.02%; injuries to the tibial nerves -- in 9.86%, injuries to the nerve trunks of the upper and lower extremities -- in 0.71%, and combined injuries to the sciatic and femoral nerve -- in 0.53%.

A specific feature distinguishing the clinical picture of injuries to the median nerve in combination with other nerves of the upper extremity is the polymorphic character of the symptoms. It should be noted that the indications of injury to the median nerve always prevailed over the symptoms of injury to the other nerves. Often such cases gave an unclear neurological picture, since the character of disorders in the injured nerves is quite varied.

The place of the firearms wound to the extremity and the level /35 of injury to the nerve trunk have a rather important significance in the clinical diagnosis and surgical tactics.

According to the materials of development of illness histories, it has been possible to clarify the relationship of the frequency of injuries to the nerve trunks depending on the localization of injury to the extremity. Thus, injuries to the peripheral nerves of the upper extremities were noted in 61.0%, of the upper -- in 38.3%, and simultaneous injuries of the nerve trunks of the upper and lower extremities -- in 0.7% (fig. 2).

Approximately the same data were obtained also based on the materials of medical reports from the Leningrad front, according to which injuries of the peripheral nerves of the upper extremities were noted in 65.8%, and of the lower extremities -- in 34.2% of the cases.

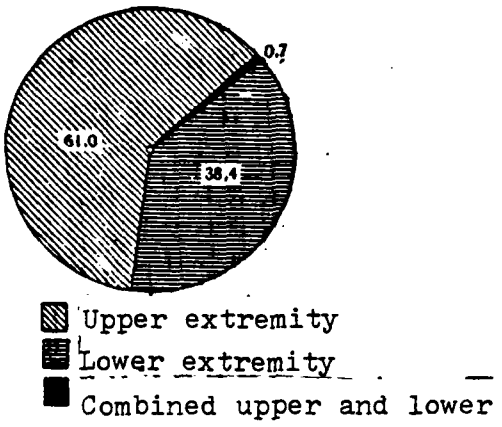



Fig. 2. The ratio of nerve trunk injuries of the upper and lower extremities.

These data generally correspond to the data of most authors, as indicated by table 3.

Table 3

The ratio of nerve trunk injuries of the upper and lower extremities according to materials of personal observations (in percentages)

| Author | Upper extremity | Lower extremity |
|---|---|---|
| A. A. Dikova..... | 65.8 | 34.2 |
| K. L. Lunts..... | 64.0 | 36.0 |
| P. S. Briksman ..... | 64.7 | 35.3 |
| I. S. Babchin..... | 59.5 | 40.5 |

The comparatively high frequency of nerve injuries in the upper extremities may be conditioned by the greater number of nerve trunks and the relatively lesser protection by the mass of soft tissue as compared with the lower extremity.

In the diagnosis, clinical practice and surgical treatment of injuries to the nerve stems, the localization of the extremity wound plays a significant role, along with other factors.

The corresponding data based on materials of development of illness history are presented in table 4.

From this table it is evident that most often the injuries to the peripheral nerves were noted in wounds sustained in the area of the elbow joint and the forearm, and least often -- with injuries sustained in the area of the neck. The latter may also be explained by the fact that such wounds are accompanied by the injury of the major vessels, which often leads to terminal casualties on the battlefield.

The level of injury of the nerve trunk also determines the clinical symptomatics of the injury to a considerable degree. This is primarily reflected in motor disruptions. They are noted in all the /36 muscles fed by the given nerve when the injury is sustained centrally to the separation of the first motor branch. The muscles innervated

Table 4

Ratio of the frequency of injury to the peripheral nerves depending on the localization of the wound

| Localization of wound | Percent of cases |
|---|---|
| Area of the neck..... | 0.8 |
| " " " torso..... | 2.6 |
| " " " shoulder joint, shoulder..... | 24.3 |
| " " " elbow joint, forearm..... | 27.9 |
| " " " radiocarpal joint, hand..... | 3.4 |
| " " " hip joint, hip..... | 16.8 |
| " " " knee joint, shin..... | 16.4 |
| " " " ankle joint, foot..... | 1.5 |
| Multiple injuries..... | 6.3 |

by branches which diverge above the area of the wound retain their function. Thus, with injury to the radial nerve in the central third of the shoulder, the function of the tricipial muscle, innervated by its highly diverging branch, is retained. Injury to the ulnar nerve above the interior condyle is accompanied by paralysis of all the

muscles which it innervates, and with injury sustained below this point there is a disruption only in the function of the palmar muscles.

The corresponding data of materials from the development of illness histories are presented in table 5.

From these data it follows that the radial nerve was injured most often at the level of the shoulder, and the median and ulnar -- primarily in the area of the forearm. The latter nerves were injured in the area of the hand much more frequently than the radial. Injuries to the sciatic nerve were observed in the overwhelming majority of cases in the area of the hip, and injuries of the femoral and tibial -- with injury to the shin.

All injuries of the peripheral nerves sustained during wartime are divided by the type of weapon, the character of the injury, the external appearance of injuries to the soft tissue of the extremity, and the degree of damage to the nerve trunk.

Firearms wounds to the peripheral nerves are primarily divided /37 into two basic groups -- bullet and fragment wounds.

Bullet wounds inflicted by rifle, machine gun, automatic weapon and revolver bullets, comprise, according to materials of the development of illness history, 56.9%. Fragment inflicted wounds caused by various artillery shells, mines, granades, aviation bombs, comprise 41.5% according to the same data. Injuries inflected by blunt weapons -- rifle butts, heavy objects from falling buildings or shelters were noted in 1.6%, according to the data indicated above (fig. 3).

The prevalence of bullet wounds over fragment wounds was a characteristic specific feature of the injuries to the peripheral nerves during the Great Patriotic War, in which the participating armies were heavily equipped with automatic firing weapons. This circumstance was reflected also in the character of the injuries to

Table 5

Distribution of injuries to the peripheral nerves
depending on the level of injury to the extremity (in percentages)

| Name of nerve / Area of injury | Shoulder joint, shoulder | Elbow joint, forearm | Radiocarpal joint, hand | Hip joint, hip | Knee joint shin | Ankle joint, foot | Multiple injuries |
|---|---|---|---|---|---|---|---|
| Radial..... | 59.4 | 33.5 | 3.0 | -- | -- | -- | 4.1 |
| Median..... | 29.4 | 56.4 | 11.1 | -- | -- | -- | 3.1 |
| Ulnar..... | 16.1 | 73.3 | 7.9 | -- | -- | -- | 2.7 |
| Sciatic..... | -- | -- | -- | 89.7 | 3.2 | -- | 7.1 |
| Fibular..... | -- | -- | -- | 8.6 | 79.9 | 3.4 | 8.1 |
| Tibial..... | -- | -- | -- | 10.3 | 72.8 | 10.8 | 6.1 |

the extremities. Thus, modern bullet wounds, being less traumatic /37
than fragment wounds, very often followed the course of severe injuries due to the property of the bullet to change its axis of rotation upon impact with dense tissue and, consequently, to expand the zone of traumatic effect.

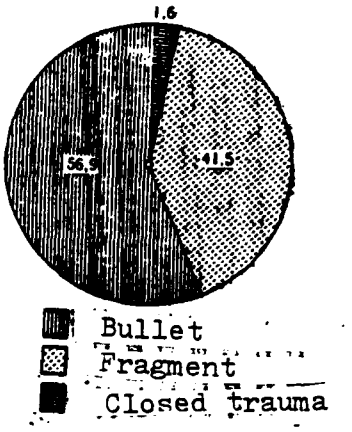



Fig. 3. Distribution of injuries to the peripheral nerves depending on the wounding shell.

Aside from this, the modern bullet has the capacity to become deformed, which had an even greater effect on the change in the configuration of the wound channel.

The modern bullet also has a no less destructive effect in cases when the wound is inflicted by ricochet, i.e., after its deflection from the axis of flight and upon impact with some solid body. We should also mention those disruptions which may be characterized as the hydrodynamic effect of a bullet travelling with very great speed and causing molecular changes in the tissues, which contain a considerable amount of liquid mediums (muscles, vessels, nerves). In this case the bullet does not product macroscopically visible destruction. The hydrodynamic action of a shell often caused a long-term "physiological severance of the nerve", and subsequently led to

deterioration of the conditions for regeneration in the directly injured tissue.

Heavy blunt injuries caused contusions of the nerves and crushing of the tissues. They were connected with the falling of logs, trees, pieces of metal, axles, wheels, etc. Closed nerve traums was noted in soldiers who had been covered up by dirt.

It follows from all this that firearms injuries to the peripheral nerves were caused primarily by bullet wounds to the extremities. This is also confirmed by the material of personal observations by most authors. Thus, bullet wounds to the nerve trunks, according to the data of P. A. Brusilovskiy, were noted in 56.6%, by fragments -- in 43.4%; according to the data of A. M. Veger and L. K. Pelepeychenko-- 56.6 and 32.3%, respectively; A. A. Dikova -- 62.6 and 35.6%, and N. B. Chibukmakher -- 65.0 and 35.0%.

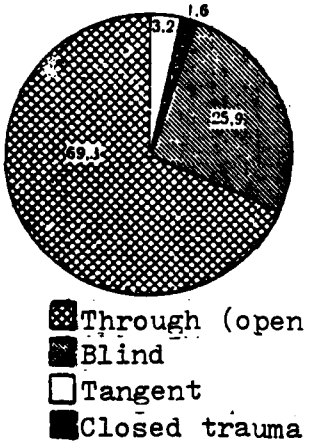
The character of the wound channel plays a significant role in /38 the diagnosis, determines the course of the injury, influences the methodology of access and the technique of surgical intervention in firearms inflicted wounds to the peripheral nerves.

According to the materials of development of illness history, injuries to the nerve trunks were observed with through (open) wounds of the extremity in 69.3%, with blind wounds -- in 25.9%, with tangent wounds -- in 3.2%, and with blunt closed trauma -- in 1.6% (fig. 4).

An analysis of the materials reflecting the character of the wound channel in the extremity in combination with the injury to individual nerves showed certain specifics which make it possible to draw corresponding substantiations for the frequency of injuries to the nerve trunks depending on the character of the injury (table 6).

Thus, injury to the nerve trunks of the upper extremity were noted primarily with through wounds within from 68.4% to 82.6%,

while with blind wounds it was considerably more rare -- from 14.7 to 28.0%. Along with this, injuries to the peripheral nerves in the lower extremities were observed within limits of from 31.1 to 45.4%. Combined injuries to the peripheral nerves and other anatomical elements of the extremities were particularly severe. Most /39 often combined were injuries of the nerves, bones and joints, and then injuries to the vessels and nerves. Finally, the group of most severe injuries was comprised by wounds to the nerves, vessels and bones in the same soldier. The number of such wounded was comparatively small, since most of them evidently perished on the battlefield in connection with severe shock and large blood losses.




/38

Fig. 4. Distribution of injuries to the peripheral nerves depending on the character of the wound channel.

According to materials of the development of illness history, /39 wounds to the nerve trunks were combined with injury to the bones in 45.2% of the cases. Such a high percentage of combined injuries to the peripheral nerves with disruption of bone integrity characterizes the severity and extent of firearms wounds.

According to the data of numerous authors, combined injuries to the nerve trunks and bones of the extremities were encountered much less frequently.

Table 6 /38

Distribution of injuries to the peripheral nerves depending on the character of the wound channel (in percentages)

| Name of nerve \ Character of injury | Through (open) | Blind | Tangent | Closed trauma | Total |
|---|---|---|---|---|---|
| Brachial plexus..... | 68.4 | 28.0 | 2.4 | 1.2 | 100.0 |
| Radial..... | 76.3 | 19.1 | 3.8 | 0.8 | 100.0 |
| Median..... | 82.6 | 14.7 | 2.4 | 0.3 | 100.0 |
| Ulnar..... | 75.6 | 17.4 | 6.5 | 0.5 | 100.0 |
| Femoral..... | 51.2 | 44.7 | 2.5 | 1.6 | 100.0 |
| Sciatic..... | 59.4 | 36.7 | 2.0 | 1.9 | 100.0 |
| Fibular..... | 62.4 | 31.1 | 5.5 | 1.0 | 100.0 |
| Tibial..... | 63.4 | 33.8 | 2.8 | -- | 100.0 |
| Leg ..... | 49.5 | 45.4 | 3.7 | 1.4 | 100.0 |
| Cervical plexus..... | 60.0 | 20.0 | 20.0 | -- | 100.0 |
| Sciatic and femoral. | 71.9 | 22.8 | -- | 5.3 | 100.0 |
| Radial and median... | 80.5 | 14.8 | 3.5 | 1.2 | 100.0 |
| Ulnar and median.... | 79.0 | 17.0 | 3.0 | 1.0 | 100.0 |
| Radial and ulnar.... | 76.1 | 21.5 | 2.4 | -- | 100.0 |
| Median, radial and ulnar..... | 77.7 | 18.0 | 2.8 | 1.5 | 100.0 |
| Nerves of the upper and lower extremities..... | 29.7 | 40.6 | -- | 29.7 | 100.0 |
| Total | 69.3 | 25.9 | 3.2 | 1.6 | 100.0 |

/39

Thus, D. G. Shefer found them in 33.0%, M. N. Volkov -- in 31.0%, I. S. Babchin -- in 21.7%, M. S. Gorbachev -- in 25.5%, K. P. Chikovani -- in 18.0%, and G. S. Margolin -- in 10.7%.

An analysis of the materials of illness histories makes it possible to clarify certain relations in the frequency of combined injuries of individual nerves and bones of the extremities (table 7).

Table 7

Frequency of injuries to the peripheral nerves accompanied by various types of bone damage (in percentages)

| Name of nerve / Character of injury | Fracture without comminution | Comminuted fracture | Other types of fractures | Without injury to bones | Total |
|---|---|---|---|---|---|
| Cervical plexus.... | 20.0 | -- | -- | 80.0 | 100.0 |
| Brachial plexus.... | 23.8 | 11.2 | 2.9 | 62.1 | 100.0 |
| Radial..... | 30.3 | 26.7 | 4.0 | 39.0 | 100.0 |
| Median..... | 30.9 | 18.1 | 2.2 | 48.8 | 100.0 |
| Ulnar..... | 29.7 | 18.5 | 4.5 | 47.3 | 100.0 |
| Lumbosacral plexus. | 28.0 | 4.0 | -- | 68.0 | 100.0 |
| Femoral..... | 16.4 | 9.9 | 3.2 | 70.5 | 100.0 |
| Sciatic..... | 8.8 | 5.7 | 1.9 | 83.6 | 100.0 |
| Fibular..... | 27.6 | 21.5 | 3.8 | 47.1 | 100.0 |
| Tibial..... | 20.6 | 20.1 | 3.3 | 56.0 | 100.0 |
| Leg..... | 16.4 | 17.2 | 3.7 | 62.7 | 100.0 |
| Sciatic and femoral | 14.3 | 10.7 | -- | 75.0 | 100.0 |
| Median and radial.. | 30.8 | 24.4 | 3.0 | 41.8 | 100.0 |
| Ulnar and median... | 21.8 | 17.8 | 4.4 | 56.0 | 100.0 |
| Radial and ulnar... | 27.3 | 23.9 | 5.0 | 43.8 | 100.0 |
| Radial, ulnar and median..... | 22.9 | 26.9 | 7.4 | 42.8 | 100.0 |
| Nerves of the upper and lower extremities..... | 19.4 | 25.0 | 5.6 | 50.0 | 100.0 |
| Total | 23.4 | 18.2 | 3.6 | 54.8 | 100.0 |

From table 7 it is evident that combined injuries to the radial nerve and the bone were noted most often. In second place by frequency of combined injuries are the simultaneous injuries of 2-3 nerves in the upper extremity. In third place in almost the same number of cases were combined injuries to the median, fibular, and ulnar nerve; in fourth place -- injuries to the tibial nerve, in fifth -- to the brachial plexus. Finally, injuries to the sciatic /40 nerve with damage to the femur were the most rarely noted.

Materials of the development of illness histories showed certain specifics of combined injuries to the nerve trunks and bones. It was found that simultaneous injuries to the peripheral nerves and the bones are in a certain dependence on the nerve trunk and on the level of injury to the extremity. Thus, injuries to the radial nerve and bone were noted more often than injuries to the median and ulnar nerve and bone. The frequency of combined injuries to the nerve trunk and bone respectively changed depending on the level of the injury. Thus, simultaneous injuries to the radial nerve and the brachium were noted in 37.3%, while its injuries at the level of the forearm in combination with damage to the radial or ulnar bone -- in 21.5%, while combined injury of the radial nerve and the hand bones was noted in 2.4%. Injuries of the median nerve and the brachium were found in 8.1%, simultaneously with the radial or elbow bone -- in 34.3%, and with the bones in the hand -- in 9.0%. Firearms inflicted wounds to the ulnar nerve and the brachium were noted in only 5.5%, injury to the ulnar nerve and the forearm bones -- in 43.0%, and to the ulnar nerve and the hand -- in 4.7% (fig. 5).

Thus, the combined injury of the radial nerve and the brachium were most often noted, while injuries to the median, ulnar nerve and its bone were observed 5-8 times more rarely as compared with injury to the radial nerve. This expressed difference in the frequency of simultaneous injury to the nerve trunks of the upper extremity and the brachium may be explained by the immediate proximity of the radial nerve to the brachium and by the more remote location of the median and ulnar nerves, with the exterior location of the former on the shoulder and the interior location of the latter two. Such sharp fluctuation of frequency of injuries to these same nerves and to the forearm bones was not observed. The most often indicated combinations involved injuries to the ulnar, then to the median, and more rarely to the radial nerve. The explanation for this should also be sought in the topographical relationships of the nerve stems and the forearm bones. The relation of frequency of injuries to the nerve trunks in combination with fingers of the hand was as follows: most often noted were injuries to the median nerve; there were half as many injuries

to the ulnar and over four times fewer injuries of the radial nerve in respect to the median. These combined injuries and their relationships may be explained not only by the proximity of the nerve to the bones, but also by the zone of their innervation, which is most extensive at this level in the median nerve.

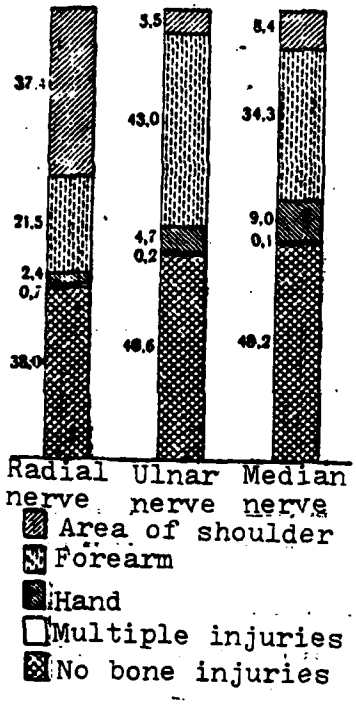



Fig. 5. Injuries to the peripheral nerves of the upper extremity accompanied by injury to the bones.

With firearms inflicted wounds to the peripheral nerves of the lower extremities, the simultaneous injuries to the bone were also noted, and the same factors played a role in their relation of /41 frequency -- the corresponding nerve trunk, its proximity to the bone and the level of injury. Thus, injury to the femoral nerve with simultaneous injury to the bone was noted in 28.5%, of the sciatic nerve and bone -- in 15.5%; injuries to the fibular nerve were combined with trauma to the femur in 3.0%, of the tibial -- in 2.3%, of the nerves in the leg -- in 2.2%; injuries of the latter nerves combined with shin bone injuries were in different proportion.

Injuries of the fibular nerves were observed in 47.8%, of the tibial -- in 36.2%, of the nerves in the leg -- in 28.4%. Simultaneous injury of the leg nerves with the bones of the foot were noted in 8.7%, tibial -- in 6.6%, and fibular -- in 2.5% (fig. 6).

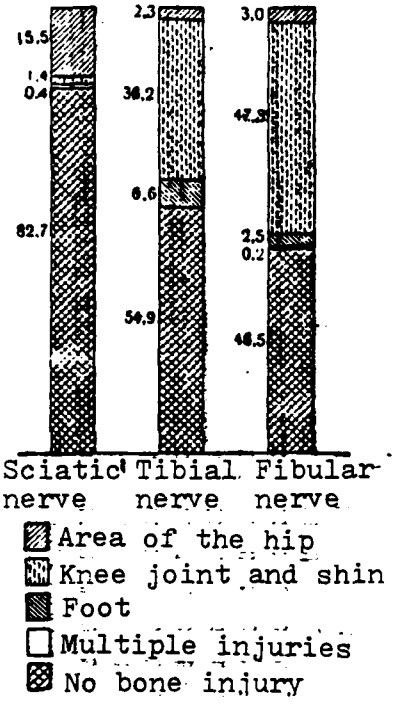



Fig. 6. Injuries to the peripheral nerves of the lower extremity accompanied by damage to the bone.

The clinical course of combined injuries of the nerve trunks and bones differ by their corresponding severity. At the same time, bone fragments which entered the nerve trunk caused sharp pains. The involvement of the ends of the injured nerve or its trunk into the bone calous due to its constant mechanical irritation was accompanied by intensive pains.

Combined injuries of the nerve trunks and bones not only were distinguished by certain clinical specifics, but also determined the tactics of the surgeon. They were also reflected in the result of

treating injuries to the peripheral nerves.

According to materials of the development of illness histories, the number of injuries to the brachial plexus and the bones was expressed as 37.9%. Combined injuries to the brachial plexus and the bones of the shoulder girdle, according to the same data, were noted as 36.2%. The high injuries to the brachial plexus in combination with damage to the transverse processes of the cervical vertebrae should be noted. G. A. Rikhter described the extensive injury of the brachial plexus and the transverse processes of the cervical vertebrae with simultaneous disruption of the integrity of the hard meninx of the spinal cord. As a result of this, a large "false cyst" was formed, filled with spinal fluid. The restoration of lost function was achieved by operative means.

Among the injuries to other bones we should note the combined injury of the brachial plexus and the shoulder blade, which often led to the formation of numerous bone fragments, particularly with the location of the bullet exit wound on the back.

A. Yu. Sozon-Yaroshevich described the firearms inflicted fracture of the I rib, whose edges were pressing on the roots of the brachial plexur. With epiphysial fractures of the brachium accompanied by formation of excess callous, compression of the peripheral part of the brachial plexus was observed (G. A. Rikhter, A. Yu. Sozon-Yaroshevich). Combined injuries of the brachial plexus, bones of the /42 shoulder girdle, and chest organs were also encountered.

According to the materials of development of illness histories, injuries to the brachial plexus were accompanied by damage to the torso bones in 14.9%; with this character of injury, damage to the bones of the brachial articulation and the shoulder was expressed in 21.3%.

Combined trauma of the radial nerve with bone fractures was in first place among other similar combined injuries. Thus, according

to the materials of the development of illness histories, injury to the radial nerve and the bones was observed in 61.0%. Of this number, transverse fractures comprised 30.3%, and comminuted fractures -- 26.7%.

With bone fractures in the forearm, primarily the deep branch of the radial nerve was affected, along with its branches -- the dorsal interosseal nerve of the forearm. The interosseal dorsal nerve of the forearm closely adjoins the epiphysis of the radius, innervates the back of the radiocarpal articulation, the bones and ligaments of the wrist and the carpometacarpal articulations, as well as the proximal heads of the metacarpal bones. This is what explains the sharp rarefication of these bones with severe injuries to the radial nerve. G. I. Turner first focused attention on injuries to the dorsal interosseal nerve of the forearm during fracture of the radius in the classical place (Kolles fracture). S. L. Firer presents several similar cases in which the process of development of the bone callous is inhibited by the irritation of this branch. With fractures of the neck of the radius and the forearm bones in their proximal region, disruptions in the function of the deep branch of the radial nerve were observed, according to A. I. Geymanovich.

Injury of the ulnar nerve with bone damage was noted, according to the materials of the development of illness histories, in 52.7%, i.e., not as often as injuries to the radial nerve. The ulnar nerve was injured primarily with epicondylic fractures, particularly with displacement of the distal fragment. The combination of injuries to the ulnar nerve and bone fractures in the area of the elbow joint and the forearm was noted, according to the same data, in 43.0%.

Injury of the ulnar nerve was usually observed primarily with disruption of the integrity of the exterior condyle of the shoulder and secondly with poor and insufficient reposition, with improper fusion of fractures.

The injury of the ulnar nerve which was observed with dislocations of the elbow joint, particularly with displacement of the elbow bone towards the inside, should be noted.

G. I. Turner focuses attention on the injury of the elbow bone (ulna), its styloid process, which may cause compression of the branchings in the ulnar nerve leading to the hand.

The fracture of the radius in the distal segment with its dorsal displacement and with pinching of the nerve to the radial edge of the pisiform bone and to the ulnar edge of the hooked bone hook should be indicated as a rare trauma of the ulnar nerve.

Clinically, fractures pertaining to the shoulder, or more accurately, to the area of the brachial articulation, most often gave symptoms of total paralysis of all the muscles innervated by the ulnar nerve. With fractures of the bones in the forearm, incomplete paralysis is observed.

Injury to the median nerve in bone fractures, according to the materials of development of illness histories, was noted in 51.2%. This nerve was most often injured in combination with the ulnar nerve, and then with the radial. The median nerve was damaged comparatively rarely with fractures of the brachial articulation and the brachium -- in 8.1%. The most frequent combined injuries of the median nerve and /43 the bones related to the area of the elbow joint and the forearm -- 34.3%. B. A. Favorskiy, in 1/3 of all cases of injury to the median nerve, found simultaneous fractures of the bones in the forearm. Similar injuries were observed with fractures of the ulna or the radius as well as particularly with the simultaneous injury of both bones in the forearm.

With combined injuries of several nerve trunks and bones of the forearm, expressed manifestations of rigidity and contractures in the radiocarpal articulations were often observed in varying degrees.

Combined injuries of the sciatic nerve were noted much less frequently than its isolated injury. According to the materials of development of illness histories, injuries to the sciatic nerve with bone fractures comprised 16.4%. Here, transverse fractures were the

most frequent, and were observed in 8.8%. Comminuted fractures yielded 5.7%. According to the data of B. A. Favorskiy, the percentage of such combined injuries equalled 5.1. V. N. Shamov gives a somewhat larger figure -- 6.2%. The data of S. L. Firer is close to this -- 6.7%.

The frequency of combined injuries to the tibial, fibular nerve and bones of the lower extremity was in direct dependence on the level of division of the sciatic nerve. Combined injuries to the tibial nerve and the bone were noted in 44.0%. Its injury with fractures of the femur, particularly in the epicondylic region, was noted in 2.3%, with shin bone fractures, primarily in their central third -- in 36.2%, and with injuries to the talocrural articulation and the bones of the foot -- in 5.5%.

Combined injuries of the fibular nerve and the bones with firearms wounds to the extremity were noted frequently -- 52.9%. The fibular nerve in numerous places and along a great extent adjoins the shin bones, as well as the exterior femoral condyle and the knee joint. Such anatomical relations conditioned the localization and frequency of combined injuries to the fibular nerve at different levels of the lower extremity. Combined injuries of the fibular nerve and the bone were noted least frequently in the region of the foot and the ankle joint -- in 2.5%. They were combined with fractures of the hip and its lower third in 3.0%. Most often (in 47.8%), the fibular nerve was injured during fractures of both shin bones in the upper and central third. Next, with fractures of the head and neck of the fibula, with fractures of the upper and central third of the tibia, and finally with external epicondylic fractures of the femur. Severe injuries of the fibular nerve were observed with combined fractures and dislocations of the shin bones, particularly toward the rear. In these cases, the full severance of the nerve was noted, together with severance of the vascular fascicle of the popliteal fossa. Through firearms wounds to the upper third of the shin with splintering of both bones and severance of the fibular nerve accompanied by shin bone fractures attract particular attention. They are observed

most often with bullet wounds and were noted, according to the materials of development of illness histories, in 38.1%. The most frequent level of injury to the nerves in the leg was the central third of the shin, less frequently -- the upper. In the lower third there was damage not to the trunks, but to their peripheral branches.

With injury to two nerve trunks in the shin, the severity of the injury to individual nerves was somewhat varied and non-uniform: in the zone of one manifestations of prolapse was sometimes noted, and in the zone of another -- symptoms of irritation.

The character of surgical treatment of bone injuries had a /44
great significance for the function of the extremity associated with the subsequent restoration of the nerve trunk. In all cases of firearms wounds to the nerve trunks and bones at the primary stages, preliminary surgical treatment of the wound was conducted in 64.4%, and removal of bone fragments -- in 5.2%.

In a detailed evaluation of bone regeneration, it is also necessary to consider all the phenomena complicating the course of the fractures, as for example: the character of secondary infection, the proliferation of soft tissues surrounding the bone, extensive hemorrhaging, etc.

Of significant importance in the clinical treatment, diagnosis and surgical treatment were simultaneous injuries to the nerve trunk and to the large blood vessels, which were noted, according to the materials of development of illness histories, in 5.4%.

In first place by frequency of combined injuries to the nerve trunks and vessels are injuries to the brachial artery -- 1.8%, in second -- combined injuries to the ulnar and radial artery -- in 1.5%, in third -- wounds to the tibial artery -- 1.2%. Simultaneous injury to the ulnar nerve and the ulnar artery was noted in 4.0%, of the median nerve and the brachial artery -- in 2.8%, of the radial nerve and the brachial artery -- in 2.9%, of the sciatic nerve and the femoral artery -- in 1.6%, of the tibial nerve and the artery of the same name -- in 8.0%.

The frequency of combined wounds to the nerves and vessels, according to the materials of observations of individual authors, fluctuates within a wide range.

Thus, according to the data of K. P. Chikovani, it comprised 22.0%, according to the data of M. N. Volkov -- 13.0%, G. S. Margolin-- 10.7%, N. I. Makhov -- 10.0%, M. S. Gorbachev -- 9.9%, I. S. Babchin -- 6.3%, D. G. Shefer -- 5.4%, A. Yu. Sozon-Yaroshevich -- 3.0%.

According to the materials of development of illness histories, injuries to the nerve trunks and the blood vessels were noted in the following relations (table 8).

Table 8

The relative share of combined injuries to the peripheral nerves and the blood vessels (in percentages of the overall number of injuries to each nerve)

| Name of nerve | Percentage of cases |
|---|---|
| Brachial plexus | 7.9 |
| Radial | 3.1 |
| Median | 7.0 |
| Ulnar | 4.7 |
| Lumbo-sacral plexus | 4.0 |
| Femoral | 3.3 |
| Sciatic | 2.1 |
| Fibular | 6.2 |
| Tibial | 9.9 |
| Leg nerves | 6.2 |
| Sciatic and femoral | 5.4 |
| Median and radial | 7.1 |
| Ulnar and median | 9.2 |
| Radial and ulnar | 4.0 |
| Radial, ulnar and median | 6.1 |
| Nerves of the upper and lower extremities | 6.8 |

Most frequently, combined injuries to the neurovascular fascicle /45 were noted in the regions of close anatomical location of the nerve trunks and the blood vessels, specifically: in the subclavial and underarm cavity, in the sulcus bicipitalis lateralis, in the area of the elbow bend, and in the popliteal fossa.

Injuries to the nerve trunks of blood vessels introduced a number of unique disorders into the picture of injury to the neurovascular fascicle -- ranging from light degrees of sensory, motor and trophic disruptions to sharply expressed forms of severe ischemic paralyses and contractures. The indicated disorders often made it difficult to distinguish the symptoms of injury to the peripheral nerve from indications of injury to the blood vessel.

Characteristic specifics of disorders caused by injury to the blood vessels were the following: a) distribution of sensory and motor disruptions which did not correspond to the innervation zone of the peripheral nerve, b) the presence of expressed trophic changes, c) the manifestation of sharp vascular disorders.

Combined injuries to the vessels and nerves yielded afflictions of varying intensity, with a rather unique clinical picture, depending on the character and form of the wound. If the path of the wounding shell passed near a neurovascular fascicle, often there were signs of contusion and commotion in the nerve, which were combined with hemorrhaging not only in the nerve membrane and its inter-fascicle spaces, but also in the fatty tissue surrounding the vessels and nerves.

Passing through this fatty tissue are both the arterial and venous trunks which accompany and vascularize the vessel wall. These are located parallel to the nerve trunks and the main vessels, branch almost perpendicularly to the vessel wall, and supply the nerve stems, passing through them (B. V. Ognev). When the wounding shell passed through the network of these vessels, it often caused

massive hemorrhaging, even without injury to the main arteries and the nerve trunks. The formed hematomas subsequently formed thick scars, fusing together the vessels and the nerves. Accompanying infection even more greatly facilitated the formation of thick bands and scars.

Nerve trunks were often not damaged directly, but were tightly pinched by the formed hematomas, arterial and arterio-venous anurisms, which was often observed in operations performed on the brachial plexus.

Vessels of medium and small caliber, with their total severance, sometimes became thrombosed at the ends and fused to the nerve trunks. Thus, G. A. Rikhter indicates that he often had occasion to observe how, together with a large neuroma, there was an injured blood vessed which had become thrombosed over a significant extent, while A. Yu. Sozon-Yaroshevich describes thromboses which had spread to 20-25 cm.

Particular attention should also be directed to one more type of combined injury which was often observed during the Great Patriotic War -- the combined injury of nerves and veins, which was sometimes encountered while the arterial vessels remained intact. These injuries were often noted in the proximal sections of the upper extremities.

Being restored in most cases autochthonally (A. Yu. Talalayev), the veins formed large "venous lakes" in the midst of the cicatrical connective tissue. These "lakes" surrounded the nerve trunks which were fused into the scars as if in a shell. In these cases, the /46 battle against hemorrhaging was often exceptionally difficult.

As concerns the character of injuries to the nerves in combination with injuries to the vessels, these were most varied: contusions of the commotion and contusion type, hemorrhaging, extension and super-extension, axon breaks, severance of nerves, complete and partial disruptions of the integrity of the nerve trunk, and all types of compression. However, within this polymorphous picture,

the main link with the injury to the vascular trunks, which was clinically manifested more clearly. Of course, more complex combinations were also observed, when together with injuries to the vessels and nerves in various combinations there were injuries to the bones, joints, and muscles.

Firearms inflicted wounds to the peripheral nerves, according to the materials of development of illness histories, were combined with a series of severe complications on the part of the corresponding extremity as well as the organism as a whole. These complications were noted in 29.0% (table 9).

Table 9

The relative share of various complications accompanying wounds to the extremities with damage to the peripheral nerves

| Character of complications | Percentage of cases |
|---|---|
| Osteomyelitis | 16.6 |
| Purulent infection | 4.5 |
| Hemorrhaging from the major vessels | 2.5 |
| Anaerobic infection | 1.1 |
| Traumatic shock | 0.5 |
| Other surgical complications | 3.8 |
| No complications | 71.0 |

According to these same materials it was established that complications were most often noted with combined injuries to the fibular nerve (38.8%), with combined injuries to the nerve trunks of the upper extremity (31.7%), and then with injury to the radial nerve (31.4%). They were least frequently observed in injuries to the sciatic nerve (25.6%) and the median nerve (21.6%).

From table 9 it is evident that injuries to the nerve trunks were accompanied by traumatic shock in 0.5% of all cases of injury to

the peripheral nerves. Of these, shock was observed in 2.5% with injury to the femoral nerve, in 1.8% with injury to the sciatic and femoral nerve, and in 0.3-0.5% with injury to the other nerve trunks as compared with all injuries to the nerve trunks.

Injuries to the nerve trunks and the blood vessels were accompanied by significant hemorrhaging in 2.5% of the cases. The latter was noted in 5.6% with injury to the median and ulnar nerve, in 3.6% with injury to the median, radial and ulnar nerve, in 3.0% with injury to the median and ulnar, in 2.6% with injury to the median, in 2.0% with injury to the ulnar, and in 1.3% with injury to the radial nerve. Thus, injuries to the peripheral nerves were accompanied most often by hemorrhaging with injury of the nerve trunks of the upper extremity, primarily with combined injuries of 2-3 nerves, and primarily with injury of the median nerve.

According to the materials of development of illness histories, injuries to the peripheral nerves were accompanied by one of the very severe and long-term complications -- osteomyelitis, which was observed in 16.6%.

According to these materials, injury to the peripheral nerves of /47 the upper extremity was accompanied by osteomyelitis in 66.42% of the cases, and of the lower extremity -- in 33.58% (fig. 7). Wounds to the radial nerve were accompanied by osteomyelitis in 23.8%, of the fibular nerve -- in 23.6%, of the tibial nerve -- in 17.4%, of the ulnar nerve -- in 16.8%, of the median nerve -- in 13.9%, of the femoral nerve -- in 12.9%, and of the sciatic nerve -- in 7.4% (fig. 8).

A comparatively high percentage of injuries to the peripheral nerves accompanied by osteomyelitis was noted with combined injuries of 2-3 nerve trunks. Thus, injuries to the median, radial and ulnar nerves were accompanied by osteomyelitis in 22.3%, the radial and ulnar -- in 22.0%, injuries to the nerve trunks of the upper and lower extremities -- in 21.6%, the radial and median nerves -- in 19.1%, of the nerves in the leg -- in 16.3%, the ulnar and median -- in 12.2%.

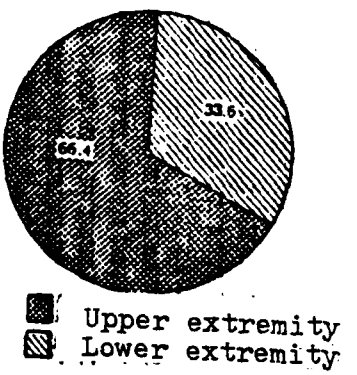



Fig. 7. Injuries to the peripheral nerves of the upper and lower extremity complicated by osteomyelitis.

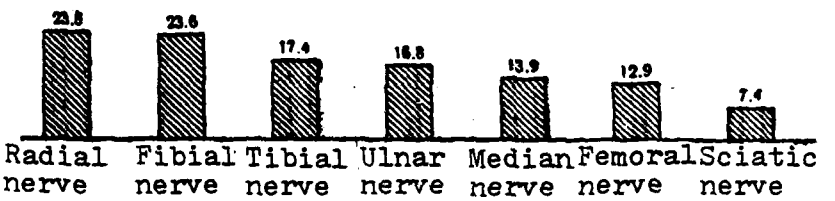



Fig. 8. Injuries to the individual peripheral nerves complicated by osteomyelitis.

Consequently, injuries to the peripheral nerves of the upper extremity were accompanied by osteomyelitis of the bones more frequently than injuries of the lower extremities. This combination was most often noted with trauma of the radial nerve and considerably less often with injury to the sciatic nerve. These complications of injuries to the nerve trunks determined not only the severity and character of the damage, but also conditioned the tactics and methodology of surgical treatment.

Firearms inflicted fractures complicated by osteomyelitis, with the presence of injury to the nerve trunk, necessitated first the performance of an operation on the bones, and then later restorative operations on the nerve, of course with appropriate indications.

The healing of osteal fistulas took place slowly, and sometimes did not occur at all. In this group of wounded, long-term waiting could lead to irreversible, stable changes in the nerve trunk. On the other hand, simultaneous intervention on the bone and on the nerve with the presence of infection threatened severe ascending processes. Despite this fact, some surgeons operated on nerve trunk injuries with unhealed wounds and with osteomyelitis (P. K. Anokhin, A. G. Heklepayeva et al.). However, these tactics nevertheless did not gain widespread recognition. Although the authors proposed operating through an incision which did not coincide with the wound opening, the nerve was nevertheless reached through an opening which was undoubtedly infected.

Other surgeons tried to perform the earliest possible interventions on nerves without simultaneous operation on the bones in order to improve the course of the osteomyelitic process (A. N. Bakulev, A. G. Fetisova). /48

In some cases, for the most part necessitated, it was necessary to operate simultaneously on the bones and on the injured nerve in the presence of osteomyelitis. A number of authors cite individual cases of such interventions: M. N. Kirsanova -- 40, A. S. Lur'ye -- 11, G. A. Rikhter -- 10, A. G. Fetisova -- 13, S. L. Firer -- 8, etc.

In recent years, individual works have appeared which are devoted to the question of surgical intervention on the nerve trunks and known infected osteomyelitic centers (M. N. Volkov, D. S. Zel'dich, I. M. Ishchenko, P. S. Kaluzhskiy, M. N. Kirsanov, A. S. Lur'ye, A. G. Fetisova and others). However, this methodology did not receive widespread application from most of our country's surgeons. Along with this, firearms-inflicted wounds of the peripheral nerves in 71.0%

were not accompanied by the indicated severe complications, but followed the course of ordinary granulating wounds. Here it was discovered that injuries to the median nerve followed a course free of wound complications in 78.4%, the sciatic -- in 76.4%, the ulnar -- in 75.6%, the tibial -- in 69.9%. Last place in frequency of injuries belonged to the radial nerve -- 68.6% (fig. 9).

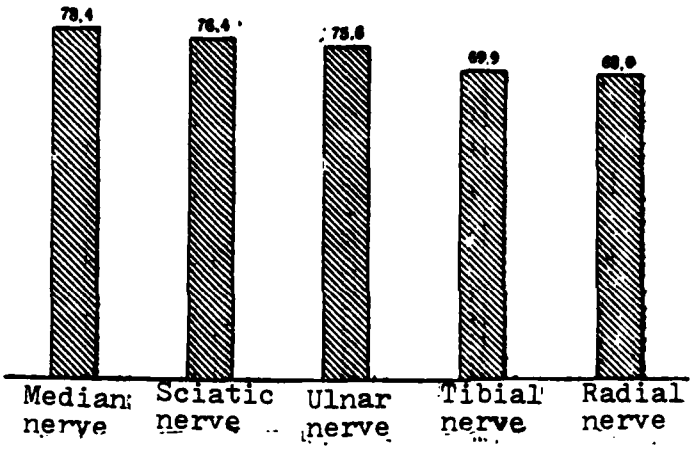



Fig. 9. Injuries to the individual peripheral nerves following a course free of complications.

The experience of Soviet medicine in the Great Patriotic War allows us to note certain distinguishing specifics of firearms inflicted wounds to the peripheral nerves. These specifics are characterized by:

a) the presence of a large number of combined injuries to the peripheral nerves and injuries to the bones, blood vessels and joints of the extremities;

b) the increased frequency of simultaneous injury to 2-3 nerve trunks, primarily in the upper extremity;

c) the prevalence of bullet wounds to the nerve trunks over other traumatic injuries;

d) the prevalence of injuries to the nerve trunks of the upper extremity with through wounds as compared with the lower extremity, where trauma of the peripheral nerves with blind wounds prevailed;

e) the presence of a considerable number of injuries to the /49
nerve trunks accompanied by severe complications at the moment of injury as well as subsequently; of these, excessive hemorrhaging, traumatic shock, purulent infection, osteomyelitis, and others were of particular significance.

These specifics of firearms inflicted wounds to the peripheral nerves determined the diagnosis, clinical treatment and indications for conservative and surgical treatment. They also conditioned the volume of medical evacuation provision in the Great Patriotic War.

The strict organization of the surgical and neurosurgical aid for nerve trunk wounds ensured their successful treatment under front line conditions, starting with the army region, as well as on the home front, which had never existed anywhere before in any other war. It was put forth for the first time by the practice of Socialist public health and by the experience of the Great Patriotic War. The strong development of medical science in our country and the presence of the appropriate cadres made it possible to organize special types of aid. The system of specialized surgical aid during the Great Patriotic War, and of neurosurgical aid in particular, was one of the greatest and most important achievements of the Soviet Army Medical Service.

## CHAPTER III
## THE HISTOPATHOLOGY OF PERIPHERAL NERVE TRUNKS IN COMBAT TRAUMA

### Preliminary remarks

During the Great Patriotic War and in the first post-war years, Soviet neurosurgeons and neurohistopathologists accumulated much experience in the morphology of those pathological processes which develop in the peripheral nerve trunks during wounds to the extremities.

All the tissue changes and re-structuring in the peripheral nerve trunk which take place from the moment of infliction of the trauma to the development of the final residual conditions are a reflection of the processes of wound healing, organization of tissue defect, disintegration and elimination (decomposition and purification) of the products of decomposition in the central and peripheral segment of the injured nerve and regeneration of the nerve fibers. The processes of wound healing create an environment in which degenerative and regenerative changes in the nerve fibers are developed, and therefore they are a very important factor, determining the rate of development and final effect of these changes. The regeneration processes lead to the restoration of the morphological continuity of all the components which participate in building the peripheral nerve trunk, and therefore to the restoration of its functions, i.e., the morphological and functional unification of the center and the periphery which is severed at the moment of trauma infliction.

With disruption of the integrity of the peripheral nerve trunk, whatever the mechanism of the trauma (be it a careful incision by a surgeon's sharp scalpel or the rough crushing of the nerve trunk and the surrounding tissue by fragments from an artillery shell or aviation bomb), it is necessary to distinguish three areas in which pathological processes which differ in their details are unified into a single complex of wound healing of the peripheral nerve trunk: a) the area of direct application of the trauma; b) the peripheral segment of the nerve from the point of injury to the peripheral nerve endings and the

working organ; c) the central segment up to the nerve cells, from which the severed nerve fibers originate.

At the point of application of the traumatic agent in the first days, hemorrhagic imbibation of the damaged nerve is observed with collection of erythrocytes between the nerve fiber fascicles and with the appearance of products of decomposition of myeline and axial cylinders. At both ends of the segments of damaged nerve there is degeneration and decomposition of the schwann cells and elements of connective tissue. In later stages, the appearance of energetic phagocytosis is observed, in which cells of epi-, peri- and endo- /51 neurium proliferating from the neighboring segments of the nerve participate. The schwann elements of the nerve in the areas adjoining the damaged sections are generalized, turn into granular globes and acquite energetic phagocytic properties. At the same time there is evident a lymphocytic reaction, which is more clearly expressed with more extensive and gross disintegration of the nerve. If the wound is suppurative, a leukocytic reaction is observed, and if there is a foreign body present, an inflamatory reaction occurs with appearance of gigantic multinuclear cells. Granular tissue develops, elements of which are mixed with the blood pigments and products of tissue decomposition. After this a scar is formed, which first consists of tender connective tissue with a richly developed argyrophilic fibrillarity and a network of thin-walled vessels. Subsequently, the newly formed tissue turns into a cell-deficient cicatrical tissue with thick-walled vessels. Parallel with the processes of wound healing or with certain delays in wound healing (which depends primarily on the condition of the wound), there is neurotization of the scar.

The end result of wound healing of the peripheral nerve trunk, if it is favorable, consists of the restoration of the morphological and functional continuity of the damaged nerve. The complex process of this healing consists of the replacement of the tissue defect and of the regeneration of functional parenchyma of the peripheral nerve, i.e., the axial cylinders.

There are three theoretical assumptions which lie at the basis of the modern concept of restoration of the morphological and functional continuity of the damaged peripheral nerve.

One of them is the centrogenetic theory of regeneration, the theory of axon growth in the central segment, Kakhal's theory, and the theory of the orthodox neuronists. According to this theory, the regeneration of the nerve fiber and the neurotization of the scar takes place only by means of growth of axial cylinders in the central segment and only when the latter has retained its connections with the nerve cells. Any significance of the schwann cells for regeneration is discounted. This theory does not fully encompass all the complex phenomena observed in regeneration.

Another theory is the polygenetic theory, the theory of the antineuronists, the theory of the restoration of the nerve fiber as a result of the axoblastic capacity of the schwann cells. The role of the center in regeneration is denied. Regeneration is considered to be autogenic However, autogenic regeneration, as it is presented by antineuronists, is impossible, and the facts used to prove it may be explained from the standpoint of the neuronists without bringing in the axoblastic capacities of the schwann cells. The name autogenic regenerate is used to describe sometimes the preserved axoplasm deprived of its neurofibrils and sometimes the retained neurofibrils and fibers which are analogous to those found in neuronomas.

The third point of view is an intermediate one. Shpil'meyer, acknowledging the axoblastic properties of the schwann cells, explains them by the regulating effects emanating from the center. Consequently, Shpil'meyer stresses the importance of the role of the center and the necessity of retaining the connections of the peripheral segment with the latter. But only the schwann cells are attributed the role of direct and solitary source of origin of newly formed axons. This theory is difficult to understand.

An objective perception of the facts speaks in favor of the fact that the basic and primary factor in the process of regeneration of the nerve fiber is the growth of the axon from the central segment. /52 The process of restoring the nerve fiber is a continuous growth of the axon from the central segment through the scar, which unites the ends of the central and peripheral segment to the ends of the nerve fiber in the innervated organ. This is basic and absolutely necessary in the process of regeneration, without which regeneration itself would be impossible. However, the axon growth is far from sufficient in itself, since regeneration is subordinate to a number of other, although secondary, but very important factors.

Thus, for the further growth of the axon from the central segment, schwann cells are necessary as viably important apparata of axon metabolism and myelin membranes. The protoplasm of the schwann cells is enriched by oxidasifiers, sustains the oxidizing processes in the growing axon, and has myeloblastic, although not axoblastic functions.

The connective tissue which grows between the segments of the severed nerve and which unifies its ends is also of considerable importance. The architectonics, the character of the fibers and the vascular supply of the connective tissue scar determine the mechanical organization of the medium which directs the growth of the axon, which facilitates or hinders it.

To illustrate the course of neurotization in a dense scar with random location of the connective tissue fibers, let us cite a case in which the ends of the segments were joined by dense and thick scar. Under microscopic analysis in this case, the scar was dense, with hyalinizing and hyalinized fibers. There was no hint at the penetration of axial cylinders from the central segment. In the peripheral segment there was noted an intensive growth of schwann elements. Everywhere in the scar and in the peripheral segment were foreign bodies (hairs and metallic dust), intensively expressed inflammation with fine and larger centers of fine-cell infiltrate containing gigantic cells. Despite the fact that the process had been

on-going for 4 months, neurotization of the scar had not yet begun.

Regeneration of the nerve fiber is always centrogenic, but in its development it depends on a number of factors which are associated both with the periphery and with the center.

The first stage in the morphological restoration of nerve continuity is its connective tissue growth, which is a part of the scar filling out the wound. Connective tissue fibrillarity occurs due to the growth of epineurium and perineurium segments of the nerve trunk, the perimysium internum and externum, the fascia, adventiation of the neighboring vessels, etc. Connective tissue growth is often rich in vessels. This stage has an important significance for the further course of neurotization as the primary stage in the restoration of the functional continuity of the nerve.

The second stage of restoring the nerve continuity is the growth of the schwann cells. On the part of the central and peripheral segment, these strong growth are introduced into the connective tissue mass which unites the nerve segments. They move toward each other and fuse. Part of the schwann cells is found diffusely and randomly in the scar, and part is found in rows and thick plates. Some of them form wide and fine-celled networks. A connective tissue mass is formed which is permeated throughout with schwann cells, united into complexes of various size and configuration. Significant in this growth is the fact that the strips and rows of schwann cells coming from the center are united with the Bungner strips growing /53 from the peripheral segment.

The third and final stage of restoration of the morphological nerve continuity is the stage of neurotization. Numerous axons grow into the scar on the side of the central segment. They have multiple branches and are intertwined with each other. Part of these axons enters into the protoplasm of the schwann cells in the scar and moves along them to the peripheral stump, where it enters into the Bungner bands. Having reached the peripheral segment, the newly formed axons

proceed further along the same schwann bands along which they entered the peripheral stump. Part of the axons which grow from the central segment into the connective tissue scar do not find a resting place in the schwann protoplasm and become lodged freely in the crevices metween the connective tissue fibers of the scar, the infiltrates which are sometimes present, and the hemorrhages. Often their reverse direction to the central stump is observed. All such axons are subject to granular disintegration.

Thus proceeds the neurotization of the scar -- the last step in the path toward restoration of morphological continuity, which also means the first step on the way to functional regeneration.

The abundant neurotization of the scar, the entry of numerous axons into the peripheral segment, and the presence along the entire course of the latter of a large number of axial cylinders is not always a morphological expression of the restoration of the functional continuity of the nerve. The axons which grow into the scar from the central segment are rich in branches and collaterals. They are of a mixed composition by their origin and function (motor, sensory, secretory, vasomotor).

Each of the branches which grows out of the central segment of an axon enters into the bands of schwann cells and moves along the peripheral segment to the working organ. Thus, the working organ may turn out to be tied to a lesser number of gangliose cells of the corresponding center. Also, several branches originating from different fibers of the central segment may enter into a single Bungner band. In this way, the working organ will receive axons of varying origin and will be tied with a large number of central nerve cells.

The establishment of heterogeneous and heterotopic connections is possible in the course of neurotization of a peripheral segment scar. Heterotopic bonds are understood to be a union of fibers of various function, as for example, motor fibers in schwann bands, which

conduct sensory nerve fibers. Although Nazhott and Gyuyon prove better regeneration of motor fibers in the schwann bands, which before contained fibers with the same function, i.e., a certain specialization of the Schwann elements is presumed, all this does not exclude heterogenic regeneration. Heterotopic connections are also possible, i.e., connections of functionally similar conductors with areas of the center which do not correspond to normal topicity. The fibers belonging to one center approach the working organ, which before the trauma was innervated from another center. The development of heterotopic connections may occur not only from the central segment of the primary severed nerve, but also from the central segments of severed thin trunks of the perimysium internum and externum, the fascia, vascular walls, etc., in short--the nerves of all damaged tissue formations.

Thus, in establishing anatomical-clinical relations, it should always be kept in mind that the restoration of morphological continuity is not a restoration of functional continuity, and that neurotization /54 of the peripheral segment may be heterogenic and heterotopic. In particular, it may occur from the thin nerve stems which are secondarily included in the wound scar.

All the evidence presented speaks in favor of the fact that neurotization of the scar is but one stage in functional regeneration. Further re-structuring in the center is also necessary so that there will be a complete unification of the latter with the periphery. How does this happen? The answer to this question will be given by future morphological and functional studies.

As a result of severe injury to the center and the death of nerve cells which correspond to the nerve fibers, regeneration which would have begun ceases. Then subsequent degeneration, the so-called "indirect Waller degeneration", develops in the central segment along the entire path of the regenerating nerve. The pathological condition of the center hinders and decelerates the course of regeneration.

The speed of regeneration depends on the condition and length of the central segment. The close proximity of the point of severance in relation to the center, i.e., a short central segment, gross injury and breaks in the central segment, hemorrhaging and purulent infiltration in the latter, ascending neuritis hinder regeneration and lead either to its complete cessation or to the formation of neuroma.

Most favorable for regeneration are scar structures with collagenic fibration, which is located longitudinally and parallel to the main trunk. Fatty tissue which gets into the scar, calcium salt deposits, purulent infiltrations, excessively developed vascular network with thick walls, gross development of connective tissue, particularly hyalin degenerated, which is particularly common and sharply expressed with torn wounds and long term suppuration, foreign bodies -- all these do not facilitate regeneration and inhibit the movement of both schwann cells and axial cylinders along the scar.

The time of commencement is significant for the regenerative process. If regeneration is hindered by inflammatory or other pathological processes in the scar and the central segment and begins late, then the growing axons come upon an older scar, which also becomes denser with the passage of time. Then the regenerative tendencies gradually diminish and neurotization of the scar does not occur.

The tempo and result of regeneration of a severed peripheral nerve trunk depend greatly also on the general condition of the organism and the age of the patient.

Finally, a large role is played by the timeliness and fullness of initial surgical treatment of the wound, elimination of hematomas, bone fragments, foreign bodies, etc., as well as the treatment of disrupted functions of the nerve itself (thermotherapy, mechanotherapy, exercise therapy).

The indicated processes of organization of tissue defects with injuries to the peripheral nerve trunk refer primarily to cases with total severance of the latter.

Another form of trauma to the peripheral nerve is its partial severance. The wounding shell or bone fragment, or some other foreign body disrupts the epineurium with a slipping or tangent motion and severs the fascicles of nerve fibers with perineural trabeculae which pass through here. Thus, in part of the cross section of the peripheral nerve trunk there is a complete severance of the nerve fibers. The other part of the cross section is subjected to contusion, concussion, or extension, which lead to disruptions /55 in the blood circulation, hemorrhaging, and nutrient disorders. In cases with incomplete severance of the peripheral nerve trunk, the same processes of organization and regeneration occur in the part with the severed nerve fiber fascicles and destroyed epineurium as in the case of total severance. In the part of the nerve whose morphological continuity has not been disrupted there is a resolution of hemorrhages, their connective tissue organization, and finally secondary degeneration and atrophy of the nerve fibers which pass through here.

The third form of trauma to the peripheral nerve trunk sustained on the battlefield is injury without disruption of its morphological continuity, which may be conditioned by a contusion, concussion, strain, or pinching. Contusion may sometimes lead to serious injury to the peripheral nerve trunk. It is accompanied by intra-trunk hemorrhaging and changes in the nerve fibers themselves, either of a reversible or an irreversible character, up to total severance of the individual fibers at the moment of trauma and subsequent fragmentation of the fibers which at the moment of trauma infliction have still retained their continuity.

In these cases of severe contusion to the nerve, there is observed, as in other forms of trauma, Waller degeneration in the peripheral segment and retrograde degeneration in the central segment.

The Schwann elements, multiplying, function in the same way as with severance of the nerve. The growth of connective tissue, as a rule, is not great, and its degree depends on the intensity of the injury to the nerve trunk. In cases of lighter contusion, only disintegration of the myelin is noted. The axons are retained only in the first days. They are swollen, as if powdered with dust.

In cases of gradual and long-term compression (pressing the nerve to the bone callous, compression by the scar, etc.), atrophy of the nerve fibers takes place in the nerve trunk. There is a macroscopically visible flattening of the nerve trunk or it becomes thinner as compared with the norm.

In almost all cases of contusions and compression of nerve trunks, there is usually observed in one degree or another a thickening of the epineurium, perineurium and endoneurium.

## Forms of residual conditions after firearms injuries to the nerve trunks

A study of the data obtained after operative interventions on nerve trunks in evacuation hospitals on the home front and in the Institute of Neurosurgery imeni Acad. N. N. Burdenko during the Great Patriotic War allows us to distinguish the following forms of residual conditions after firearms injuries to the nerve trunks:

1) residual conditions after complete severance of the nerve trunk with the formation of a so-called central and peripheral neuroma at the ends of the severed nerve and with cicatrical unification of these ends;

2) residual conditions after partial severance of the nerve trunk with the formation of a lateral neuroma in the severed part of the nerve and intra-trunk processes in the part of the nerve which has retained its continuity;

3) intra-trunk processes in the contused nerve with intra-trunk intra-fascicle neuromas, scars, hemorrhages and inflammatory changes;

4) atrophy of the nerve trunk included in the scar, pressed to the bone callous and fused with the vessels.

## Residual conditions after complete severance of the peripheral nerve trunk /56

In this large group of residual conditions after firearms injuries to the peripheral nerve trunks, two subgroups should be distinguished: subgroup A -- with displacement and divergence of the ends of the severed nerve without their cicatrical unification, and subgroup B -- without gross displacements of the segments and with unification of the latter by cicatrical tissue. Distinguished in both one subgroup and the other is the scar tissue between the central and peripheral segment, which is usually a sharply thichening of the end of the central segment in the form of a central neuroma, a moderate thickening, or on the contrary, a noticable reduction in the end of the peripheral segment. This latter end is improperly called a peripheral neuroma, or glioma. As we will see below, this name is incorrect, since this formation consists not of axons, but of growths of connective tissue and Schwann cells. This formation should more correctly be called "fibroschwannosis" of the end of the peripheral segment.

A. Complete severance of the nerve trunk without cicatrical unification of the segment ends. With complete severance of the peripheral nerve trunk with displacement and divergence of the ends of its segments, the location of neuromas does not correspond to the normal location of the peripheral nerve trunk. The displacement of the segments occurs primarily along the log of the nerve trunk during injury as a result of the tissue elasticity. The value of the displacement depends on the position of the extremity at the moment the wound is sustained and the degree of tension in the nerve trunk. The distance between the ends of the nerve (diastase) is

always greater than the length of the area of the nerve trunk destroyed by the trauma. Aside from displacements along the length, lateral displacements are usually also observed, which occur due to the pulling of the nerve segments gradually by the wrinkling cicatrical tissue.

The stumps of the nerve trunk, i.e., the ends of the segments of severed nerve, are free or, more often, fused with the scar tissue, bones, vessels, tendons, or articulatory bursae.

The scar tissue, which makes up the defect of the severed nerve or the space between its displaced segments, has various structure. The latter depends on the character of the wound, the intensity and extent of tissue crushing, the course of the wound healing process, and on the time elapsed after sustaining the trauma. Particularly rough and extensive are scars formed after wounding with fragments of artillery shells and aviation bombs. In such cases, the scar tissue is a dense hyalinized mass, often with a considerable amount of small caliber vessels and thick, cell-less, homogenized walls. Often a picture of obliterated vasopathy is found, there are residues of inflammatory infiltrate cells, bone fragments, shreds of clothing, hair, or pieces of dirt. Sometimes centers of bone formation are found near the bone fragments, and sometimes only calcium deposits. In this type of cicatrical mass it is sometimes only with difficulty possible to seek out the segments of severed nerve with the characteristic stumps. In other cases the scars are more tender, but even then they are comprised of more or less dense connective tissue, of centers of blood pigment and phagocytozing elements, of newly formed vessels and remnants of more or less extensively retained inflammatory infiltrations.

A considerable number of nerve fibers, which are an important component in scar tissue which fills up the wound, in some cases appears here from various sources (from the central neuroma, central /57 segments severed during wounding, thin nerve stems -- cutaneous, muscular, vascular, and other nerves). The axial cylinders here either combine into fascicles or form diffuse random weavings, or represent limited neuroma-like nodes. Axons are for the most part

bare, but often fibers are encountered which are clothed in myelin-containing neurilemma. The nerve fibers of cicatrical tissue are an important source of heterotopic neurotization of the peripheral segment of a severed nerve.

Central neuroma. Macroscopically, central neuromas appear as clavate, globular or bulbous thickening in the end of the central segment. The caliber of such thickening may exceed the normal caliber of the nerve trunk by 2-2½ times. These are thickened areas with a dense consistency, with a smokey grey, sometimes spotted surface, usually loosely tied with the surrounding tissue.

Sometimes the thickening is elongated in the direction toward the peripheral segment in the form of a nipple-shaped or conical growth. In exceptionally rare cases, there is a thinning of the nerve trunk at the end of the central segment. The lateral surfaces of the central neuroma are smooth and covered with thickened epineurium. The surface turned toward the peripheral segment is usually fringed, and sometimes slightly bumpy.

Central neuromas consist of: 1) dense or loose weave of newly formed axial cylinders grown out of the central segment; 2) plates and bands of Schwann elements of the same origin; 3) considerable connective tissue growth, primarily from the perineurium and epineurium of the central segment and rarely from the surrounding tissue. Between these basic tissue components of the central neuroma there are very often encountered freely lying small-celled inflammatory infiltrates, globules of blood iron-containing pigment enclosed within cells, and newly formed blood vessels.

The number of vessels in different cases of central neuromas is not uniform. Older neuromas, after 8-12 months of existence, are usually deficient in vessels. The latter, as a rule, have thick homogenized walls. In fresher cases, manifestation of endovasopathy is common and rich development of agyrophylic fibricity in adventition.

The connective tissue, which in various quantities permeates the central neuroma, is represented by a dense weave of collagenic and partially argyrophylic fibers. The fibers are usually located randomly and in later cases are constantly found in a state of hyalinization and hyalin globular disintegration.

The connective tissue skeleton of the central neuroma is permeated by a more or less abundant amount of Schwann elements in the form of thick and thin bands, wide plates and extensive platforms. They are partially free from the axial cylinders, and partially contain them in the form of fascicles. The axial cylinders, which are enclosed in the plasma of the Schwann elements, are often clothed in myelin-containing casings. Part of the axial cylinders of the central neuroma are located freely in inter-tissue crevices, outside the Schwann bands and plates. Such axial cylinders are usually characterized by swelling, non-uniform impregnation with pitted surfaces and with indications of fragmentation and granular disintegration.

Depending on the quantitative relationship of the basic tissue /58
elements of the central neuroma and the admixture of tissues of inflammatory origin, the following are distinguished:

1. The classical type of central neuroma with intensive neurotization of a moderately developed connective framework without the presence of tissues and cells of inflammatory origin.

2. The variant of the classical structure of the central neuroma characterized by the absence of disordered webbing of the axial cylinders and an obvious tendency toward the location of their fascicles in relation to the length of the trunk.

In fig. 10 we see how large fascicles of nerve fibers, separated from each other with layers of collagen fibers of various thickness come out into the neuroma from the central segment. Some of them

end in fascicular neuromas. Coming out from the lateral surfaces of the nerve fiber fascicles of the neuroma perpendicular to their axis are a large number of short axial cylinders, which are closely threaded in a brush-like manner along the course of the nerve fiber fascicle.

3. The fibrose central neuromas with massive growths of collagen fibricity, for the most part subjected to hyalin homogenization and often to macroglobular disintegration. The axial cylinders in such neuromas are usually few. They are either combined into thin fascicles permeating the fibrose framework of the neuroma, or form small, well deliniated islets of interlacing in the latter, which are reminiscent of the fascicular neuroma described above. The growth of Schwann elements in such neuromas is also not very intensive. Often there is rather abundant neurotization of the marginal (subepineural) zone of the fibrose framework.

Neuromas of this type are not frequent. Usually these are the initial conditions of complete severance of the nerve trunk complicated by numerous hemorrhages, long-term inflammatory processes in the nerve, and interference of small foreign bodies.

4. Central neuromas with inflammatory changes. The intensity of inflammatory changes in the central neuroma, the character of their spread, the cellular composition of the exudate in different cases of complete severance is not uniform. Most often the composition of the inflammatory infiltrate includes lymphocytes, macrophages, sometimes with an admixture of plasmatic cells, and leukocytes. For the most part there is a small-centered accumulation of inflammatory cells either in connection with the vessels or in respect to some tissue elements. Such small centers of inflammatory cells are most abundant in the marginal zones of the neuroma, where they remain the longest. In comparatively rare cases there is noted a diffuse infiltration of the entire neuroma with inflammatory cells, with their diffuse spread along the connective framework of the neuroma, including the thin connective tissue trabeculas and interlacings in the

axiocylindrical fascicles and in the fascicular neuromas. Sometimes the inflammatory infiltrate spreads far beyond the limits of the central neuroma into the trunk of the severed nerve (ascending neuritis).

The formation of the central neuroma with the long-term presence of inflammation is accompanied, as a rule, by the abundant development of a dense hyalinized connective tissue, scant axiocylindrical growth with sharper degenerative changes in the newly formed axial cylinders, and sometimes very gross changes in the vascular walls.

With the presence of inflammatory infiltration in the central /59
neuroma, its tissue is rich in thin-walled vessels overfilled with blood. Subsequently there is either a wasting of the vascular opening with the vessel turning into a solid, dense,cell-deficient cord, or its change into a thick-walled vessel with a very small opening. Inflammatory cellular infiltrations are observed in part of the vascular walls, and hyperplasia of the argyrophylic fibricity and enlargement of the intra-advential lymphatic crevices is observed in the other part. In later cases, the vascular walls are grossly thickened and represent multi-layer concentric or scaly layers of extended elements (fibroblasts). In even later cases, the gigantically thickened vascular wall with small opening consists only of homogenized hyalin-like mass which contains no nuclear elements.

5. Central neuromas containing foreign bodies: hairs, small particles of metallic fragments, soil, etc. The presence of foreign bodies is usually accompanied by the development of inflammatory reactions with the formation of foreign body microgranulomas and with the participation of multinuclear gigantic cells.

The central segment of the severed nerve which lies directly over the central neuroma is, as already mentioned, is more or less thickened at a certain distance from it. This thickening is a result of the intra-trunk formation of scars, which develops in connection with intra-trunk hemorrhaging and tissue disintegration of the nerve in the areas nearest the point of severance.

Fibroschwannosis of the end of the peripheral segment (peripheral neuroma). Macroscopically, the end of the peripheral segment is most often slightly thickened. Sometimes, on the other hand, it is thinner than the normal caliber, and rarely split or flattened. Its consistency is denser than usual. The surface of the cut is greyish-white in color. Microscopically, the end of the peripheral segment consists of connective tissue and schwann growth which, as a rule, comprise the main component of the histological structure of the so-called peripheral neuroma. In many cases, particularly older ones, there is one or the other number of axial cylinders -- either bare or covered in myelin membrane, either of normal or pathological appearance. These are either degenerating and disintegrating axial cylinders of the peripheral segment, or newly formed axial cylinders which have entered from the nerve fiber fascicles of the wound scar (heterotopic neurotization). Often in the end of the peripheral segment, as in the central neuroma, there are noted inflammatory processes and development of granulation tissue of a foreign body.

The following types of fibroschwannoses are distinguished according to their histological structure:

1. The typical structure of fibroschwannosis of the peripheral segment is presented in fig. 11, where the schwann elements form a strong band in the central sections of the segment and where the connective tissue fibers are represented by thin fascicles running parallel to the axis of the band. The connective tissue mass covers this band on all sides similar to a thick capsule.

2. Peripheral neuromas with abundant content of nerve fibers. In fig. 12 we see a schwann mass which is abundantly neuroticized by thin axial cylinders with delicate spindle-shaped enlargements. Part of these is already covered in a structureless, double-contour myelin membrane.

3. Fibrose replacement of the end of the peripheral segment. /60 The fibrose mass of the proximal end of the segment usually contains neither schwann elements nor nerve fibers. Schwann elements are present only on the sides and on the proximal end in the form of a cap (fig. 13).

4. Fibroschwannosis of the peripheral segment with grossly expressed inflammatory manifestations. Usually observed are sharply expressed inflammatory infiltrates spreading along the peripheral segment and in the perineural trabeculas. These have sometimes diffuse, sometimes small-centered perivascular location (descending neuritis).

5. Fibroschwannosis of the peripheral segment with strongly developed granulation tissue of a foreign body. The foreign bodies are encapsulated by cells of the inflammatory infiltrate and gigantic cells.

B. Complete severance of the nerve trunk with cicatrical unification of the segment ends. The residual conditions after full severance of the peripheral nerve trunk are characterized by the absence of gross displacement of the segments and great divergence of their ends. The central and peripheral neuromas are not separated from each other, as is the case in subgroup A, but are fused together with scars. The cicatrical fusions may be in the form of a more or less long and thin band (subgroup $B_1$), or -- in the absence of divergence of the ends of the severed nerve -- the latter are almost adjoining and are closely fused together (subgroup $B_2$). In the latter case, with macroscopic inspection there may be diagnostic difficulties in differentiating full severance of the nerve trunk from partial severance on the one hand, and from damage to the nerve trunk without disruption of its morphological continuity on the other.

Subgroup $B_1$. The length and thickness of the scar bands and the places of their connection with neuromas are not the same in various cases. The caliber of the bands is always less than the caliber of the neuromas and the nerve trunk itself. For the most

part the scar band emanates from the center or from one or the other edge of the severed nerve. In the central sections it is thinner, and in the direction towards the central and peripheral neuroma it gradually becomes thicker. In some cases the scar band unites the lateral surfaces of the neuroma.

By the microscopic structure of the scar band which joins the central and peripheral neuroma, it is necessary to distinguish cases with neurotization of the scar band and cases without any hint of the latter.

The unification of neuromas by the scar band during its neurotization is presented in fig. 14. In similar cases it is possible to see that the singular axial cylinders as well as their fascicles permeate the bands of schwann cells in large quantities (fig. 15). In the nerve fiber fascicles in the peripheral segment there is also noted an active schwann hyperplasia and abundant neurotization by newly formed axial cylinders.

Subgroup $B_2$. The macroscopic appearance of the nerve trunks in this subgroup is rather varied. In some cases at the point of severance there is noted a reduction in the caliber of the trunk, as if a strangulation band, and in other cases -- a spindle-shaped swelling which is difficult to distinguish from the thickening of the nerve trunk with intra-trunk connective tissue growth after contusions, concussions and extensions of the nerve, i.e., with its injury without disruption of the morphological continuity.

The unification of segments of the severed nerve with a compact /61 scar may occur without their displacement in respect to the axis of the nerve trunk, i.e., the central and peripheral segments are located along a straight line. In other cases there is displacement of the segments along the axis. The segments may be fused together at an angle, sometimes reaching 90°, as is evident, for example, in fig. 16. In this case the axial cylinders of the fascicular neuromas in the central segment are united with loose axiocylindrical webbing in the perineural trabeculas and in the scar mass surrounding the neuroma.

Fig. 10. A central neuroma with longitudinal placement of the nerve fiber fascicles. The ulnar nerve 6 months after wounding by a mine fragment.

Fig. 11. Fibroschwannosis of the peripheral segment. The growth of the schwann cells proceeds in a wide band in the central sections of the segment. The radial nerve 6 months after wounding by an explosive bullet.

Fig. 12. Heterotopic neurotization of the peripheral segment. The median nerve 5½ months after a fragment wound.

Fig. 13. Fibroschwannosis of the peripheral segment. Fibrose tissue prevails in the peripheral segment. The schwann cells are located in the form of a cap only in its marginal sections. The ulnar nerve 5½ months after wounding with an explosive bullet. The wound took 3 months to heal.

Fig. 14. Neurotization of the scar band uniting the ends of a severed nerve and the growth of nerve fibers in the peripheral segment. The radial nerve 7 months after wounding by a mine fragment.

Fig. 15. Neurotization of a scar band connecting the ends of a severed radial nerve, presented in fig. 14. The axial cylinders are found in fascicles.

Fig. 16. Angular fusion of the ends of a severed nerve. The median nerve 4 months after wounding by a mine fragment.

Fig. 17. A lateral neuroma. Visible on a longitudinal cut through an excised segment of nerve trunk are the areas of various structure:

the point of direct application of the wounding agent with the formation of the lateral neuroma and part of the cross-section of the nerve trunk without disruption of its morphological continuity. The median nerve 3 months after tangent wounding by a bullet.

Fig. 18. A lateral neuroma with heterotopical neurotization of the lateral shoot. The median nerve 5 months after tangent wounding by a bullet.

## Residual conditions after partial severance of the nerve trunk

Partial, or incomplete, severance of the nerve trunk is usually a result of tangent wounding by a bullet, shell or mine fragment, bone fragments, sharp edges of displaced bones during fractures. Along with this there is a disruption in the epineurium in one or another section of the surface of the damaged nerve and complete severance of the nerve fiber fascicles passing through the point of

application of the wounding agent. In the remaining part of the nerve trunk cross-section, where the morphological continuity of the nerve has not been disrupted, there is hemorrhaging or neuritis, sometimes with the introduction of minute foreign bodies.

Macroscopically, the residual conditions after partial severance of the nerve trunk are quite varied. The following subgroups are distinguished: a) partial severance with formation of lateral neuromas; b) partial severance with the formation of spindle-shaped thickening at the level of nerve trunk injury similar to that which is usually observed with its contusions (see Residual conditions after trauma to the nerve trunk without damage to the epineurium); c) partial severance of the nerve trunk with formation of strangulation type constrictions and narrow sections in the cross-section of the nerve trunk at the point of its injury.

a) Partial severance with formation of lateral neuromas. In the area of the nerve trunk at the point of application of the wounding agent there is evident either a unilateral spindle-shaped protrusion or a unilateral and knotty growth of dense consistency, smokey-grey in color. These are lateral neuromas. The part of the nerve trunk cross-section which lies opposite the lateral neuroma is diffusely thickened or constricted.

With microscopic study, lateral neuromas, like central neuromas, represent a most complicated interlacing of newly formed axial cylinders included into the bands and plates of schwann cells. Part of the axons is directed toward the peripheral segment. The axiocylindrical and schwann growths are included into the connective tissue framework whose trabeculas originate from the perineurium and epineurium sections of the nerve trunk which adjoin the point of injury. The epineural growths form a sort of capsule which, in places reaching a considerable thickness, covers the outside of the lateral neuroma. The surface of the lateral neuroma is usually loosely or closely fused with the remaining scar mass which fills up the wound.

The lateral neuroma, which by its structure is similar to the central neuroma, is distinguished from the latter by its smaller size, small diastases of the central and peripheral segment severed nerve fiber fascicles, as well as by a more regular and oriented direction of connective tissue fibers, schwann bands and axial /62 cylinders. Often in the lateral neuroma there are noted residues of hemorrhages, inflammatory changes and tissue reactions to foreign bodies.

In the part of the nerve trunk cross-section which is not in the zone of tissue crushing by the traumatizing agent, various changes are noted similar to those which are characteristic for intra-trunk processes in a contused or strained nerve. In some cases there is moderate growth of perineural connective tissue with development of intrafascicle neuromas which end the severed nerve fibers and their thin fascicles and which unite the peripheral and central segments of the latter with completed regeneration. In other cases there is found intensive connective tissue growth in the form of an intra-trunk scar with residues of resolving point hemorrhages and with atrophying nerve fibers. Sometimes the manifestation of neuritis is noted, which may take an ascending character. Finally, in some cases there is observed a complex combination of all the described phenomena.

Visible on a longitudinal cut through an excized nerve segment are areas with different structure: a) a place of direct application of the wounding agent with the formation of a lateral neuroma; b) part of the nerve trunk cross-section without disruption of its morphological integrity in upper- and lower-lying sections of the nerve.

Usually the distal ends of the severed nerve fiber fascicles terminate in abundant new formation of axial cylinders, often myelinized. They form a neuroma which is a conglomerate of fused intrafascicular neuromas. A close weave of axial cylinders is present only in direct proximity to the central segments of severed fascicles. This interweaving rapidly loosens and in the dense connective tissue

framework there are only singular and thin fascicles of axial cylinders, sometimes included in the schwann growths, sometimes devoid of the latter (fig. 17).

Sometimes heterotopic neurotization of a lateral shoot is observed (fig. 18).

b) Partial severance with formation of fusiform enlargements at the level of injury to the nerve trunk. Macroscopically these changes are almost identical to those which are characteristic for the next group, which encompasses traumas to the nerve trunk without damage to the epineurium and with severance of the nerve fiber fascicles lying on the surface.

Partial severance in this group is characterized by fusiform enlargements of the nerve trunk. This enlargement is associated with diffuse growths of the nerve trunk stroma (endo-, peri- and epineurium), the formation of intra-trunk neuroma which takes up a greater or lesser part of the nerve trunk cross-section, centered growth of the epineurium at its point of injury, and finally rudimentally expressed formation of a lateral neuroma. Characteristic for this group are fusions of sections of the damaged epineurium with the scar which fills up the wound channel, with the muscles, vessels, etc.

c) Partial severance of the nerve trunk with formation of strangulation type constrictions and stenosis of the nerve trunk cross-section at the point of injury. This is a relatively rare form of residual condition after nerve injury with partial /63
severance of the nerve fiber fascicles. The constrictions and stenoses of the nerve trunk at the point of tangent and surface injury are formed as a result of wrinkling of the intra-trunk scar and pulling of the nerve trunk by the wrinkled scar which fills up the wound channel, with the development of dense hyalinized connective tissue with thick-walled vessels and degenerative-atrophic changes in the nerve fibers of the non-severed fascicles.

Examining the entire group of residual conditions after traumas to the peripheral nerve trunk accompanied by destruction of part of its cross-section, we should make the following remarks:

1. The residual conditions after tangent wounds to the peripheral nerve trunk accompanied by only partial destruction of its cross-section may be varied, depending on the extent of the initial traumatic crushing of the nerve trunk at the point of influence of the wounding shell as well as on the intensity and extent of the pathological processes in the part of the cross-section which preserved its continuity and in the trunk sections above and below the level of shell effect. Tangent wounds with more extensive traumatic destruction along the trunk cross-section are usually accompanied by the formation of lateral neuromas. Tangent wounds with more superficial destruction of the nerve trunk along the cross-section and more extensive lengthwise damage result in fusiform enlargements of the trunk which simulate macroscopically intra-trunk processes which develop after contusion and strains. With extensive injuries to the surface and intensively wrinkled intra-trunk cicatrices, thin sections and strangulation constrictions may rarely appear on the trunk enlargements. Such cases are macroscopically similar to total severance of the nerve trunk with unification of the segment ends by cicatrical bands.

2. On the whole, the histopathological picture characterizing the second group of residual conditions after trauma to the peripheral nerve trunk represents a complex combination of pathological phenomena which characterize the intra-trunk processes during trauma to the nerve trunk without damage to the epineurium, and pathological phenomena inherent in complete severance of the nerve trunk with the formation of neuromas. In the latter case, as has been described above, there are also other accompanying and complicating processes: the introduction of foreign bodies, hemorrhages, inflammations, connective tissue growths. As concerns the formation of neuromas, later, intra-trunk (diffuse), intra-fascicular and collateral (perineural) neuromas are observed.

3. Aside from changes in the external appearance of the damaged nerve, with its tangent wounding there is a characteristic frequency in fusion of the damaged segment with the surrounding tissues -- scars which fill up the wound channel, muscles, vessels, etc.

4. A constant symptom in the histological picture is the intensive and extensive growth of the entire connective tissue framework of the nerve trunk, with gross enlargements of the epi-, peri- and endoneurium. Here, growth in the point of severance is more rough, dense, and exhibits more acute symptoms of hyalinization.

5. Growth of the schwann cells and the axial cylinders, as a rule, is very intensive. Abundant hyperplasia of schwann cells is noted not only in the area of the severed fascicles, but also within the nerve fiber fascicles which have retained their continuity. The /64 growth of axial cylinders leads to the formation of densely- and loose-fibered neuromas and to their diffuse permeation into the connective tissue growths.

6. Neurotization of the peripheral segment after partial severance is almost always observed and occurs quite early. Equally constant are both atrophy and degeneration of the newly formed fibers-- those participating in the creation of the neuromas as well as those neurotizing the peripheral segment.

7. Nerve fiber fascicles which have retained their continuity undergo atrophic and degenerative changes with progressive demyelinization, swelling, thinning, disimpregnation and hyperimpregnation, and finally axon fragmentation. In most cases there is finally a complete severance of the functioning elements of the nerve trunk.

Such changes, which are almost constant with tangent wounds to the nerve trunk, hardly warrant such a surgical method of intervention as clinoid excision of the lateral neuromas and cicatrical intra-trunk growths.

## Residual conditions after trauma to the nerve trunk without damage to the epineurium

Residual conditions after trauma to the peripheral nerve trunk, which comprise the third group, are the result of changes in the nerve arising in connection with contusion, consussion, or extension of the nerve trunk and often by the introduction of hair particles and minute metallic dust particles into its thickness. In this case, such introduction does not cause either macroscopic or microscopic injuries to the epineurium. We are speaking of intra-trunk processes after trauma to the nerve trunk without damage to the epineurium.

Macroscopically such nerve trunks are bloated in a fusiform fashion, with a rough, slightly bumpy surface and usually very dense. Sometimes with increased density of the injured area, the caliber of the nerve trunks turns out to be norma., and sometimes it is thinner than usual.

Characteristic for the pathological structure of the nerve trunk in this group of residual conditions are: intra-trunk, cicatrical growth of connective tissue (nerve scar) with thickening of the perineurium, endoneurium, and sometimes even the epineurium; inflammatory processes with perivascular and diffuse infiltrations, sometimes with the development of microgranulomas and granulation tissue in areas of introduction of the foreign body; remnants of intra-trunk hemorrhages in various stages of resolution and organization; inter-fascicular neuromas associated with breaks in the nerve fiber fascicles; atrophy and degeneration of the nerve fibers with demyelinization and fragmentation of the axial cylinders.

Intra-trunk processes with introduction of foreign body particles (hairs). Particularly characteristic for this subgroup are tissue reactions to the introduction of small hair particles into the thickness of the nerve trunk in the absence of damage to the epineurium, which is not found even under microscopic study.

Tissue reactions to the introduction of hair particles are uniform in their essence and varied in the details of their morphological expression. As a rule, in sections of hair particle introduction there appear gigantic multi-nuclear elements and micro-granulomas (fig. 19 and 20).

Fig. 19. Gigantic multi-nuclear cells around introduced hair particles. Ulnar nerve 4 months after through fragment wounding of the soft tissue surrounding the nerve trunk.

Fig. 20. Microgranuloma of a foreign body at the point of introduction of a hair particle. Median nerve 4 months after wound caused by an explosive bullet to the soft tissue surrounding the nerve trunk.

Often it is possible to observe cases of incapsulation of /65 the foreign body together with the gigantic cells which surround it. The capsula is multi-layered, with circularly directed collagen fibers, with newly formed thin-walled vessels containing blood, and is poor in cells. Along with encapsulation, it is possible to note a slow dissolution of the hair particles. Seven and a half months after sustaining the wound, the plasma of some gigantic cells still contains hair particles, sometimes in an almost unchanged state. The specific reaction to the introduction of hairs into the thickness of the nerve trunk is always accompanied by widespread inflammatory infiltrations of a diffuse and small-centered character. The

composition of these infiltrations includes lymphocytes, plasmatic cells, polymorphonuclear leykocytes, and macrophages. The diffuse infiltrations and inflammatory cell centers are located between the collagen fibers which are moved aside by edemal fluid, between the bands of schwann cells perivascularly, perineurally, and intra-fascicularly. The non-specific inflammatory process, as also the specific granulation tissue, is retained for a rather long time. Seven to eight months after the wound is sustained there may be found clear diffuse infiltrations and numerous lymphocytic centers.

As a rule, the inflammatory process with the presence of hain in the thickness of the nerve trunk is accompanied by significant new formation of vessels. These vessels are characterized by hyper-plasia of the endothelium, up to a condition of obliterating end-arteritis. Adventition is distinguished by expanded intra-adventitial crevices, sometimes sharply expressed proliferation of the polyblast type cells and the appearance of small-cell infiltration (intra-adventitial inflammatory infiltrate).

The inflammation process is always accompanied by extensive connective tissue growth, which leads to a sharp thickening of the endo-, peri- and epineurium and the vascular walls. The composition of such growths includes irregularly located collagen fibers. The individual fibers are affixed into fascicles and homogenized. The hyalinization of collagen fibers is often concluded by granular and macroglobular disintegration. In some places the fascicles of collagen fibers are edemic and de-fibered by the fluid which has accumulated between them. Hyalinization and edema of the connective tissue growth is especially sharply expressed in the areas of granulation tissue with gigantic cells and foreign bodies.

Schwann and axiocylindrical growths in the form of inter-fascicle, diffuse intra-trunk and collateral neuromas and loosely placed bands of schwann and singular axial cylinders are expressed differently in different cases. The spread of distrophic changes of their component elements is common to all these growths. Nuclear pyknosis and recsis, vacuolization and degenerative adiposis of the protoplasm is noted in

the schwann cells. The bands of schwann elements either do not contain axial cylinders at all, or the singular axial cylinders which are found in them are in a state of severe degeneration. The axons, as a rule, are bare. Rarely they are covered with thin structureless myelin membranes.

The nerve fibers of fascicles which have retained their continuity are loosened by growths of endoneural partitions. They become progressively dèmyelinized. The axial cylinders show symptoms of degeneration and often fragmentation. Often they are thin and atrophied.

With rare exceptions, almost in all cases there are noted residues of hemorrhages, which are found near the foreign bodies as well as at a distance from them. Most often these are nests of /66 iron containing blood pigment deposited extra- and intracellularly. They are found near vessels between the collagen fibers of cicatrical tissues, between bands and plates of schwann cells, intrafascicularly, among microgranuloma cells and centers of inflammatory infiltrates. The blood pigment is retained for a long time in the tissue. Seven to eight months after the wound is sustained, it is still possible to find small clumps of blood pigment.

Inflammatory changes (traumatic neuritis) may be found under microscopic analysis.

The morphological expression of the inflammatory process is different in different cases. This variance concerns the dispersity and character of inflammatory infiltrate distribution, the cell composition, the intensity and character of connective tissue growth, the morphology of the new vascular formations, and the structure of the vascular walls.

A constant localization of inflammatory infiltrates is the connective tissue intra-trunk growth. Often the inflammatory cells spread far beyond the limits of the growing connective tissue along the perineural and endoneural trabeculae. Inflammatory infiltrations

of perivascular localization are frequent. In such cases, there is a considerable number of plasmatic cells among the lymphocytes. Perineural and intervascular infiltrates are also observed, though not frequently. These usually consist of lymphocytes, plasmatic cells, polymorphonuclear leukocytes and histocyte type cells. Sometimes a spread of inflammatory infiltrations is noted in the central direction (ascending traumatic neuritis). The inflammatory process in the nerve trunk after its contusion or concussion, as a rule, is accompanied by intensive intra-trunk growth of connective tissue which is subject to hyalinization and disintegration.

The vascular neoplasm is usually sharply expressed, with endothelial hyperplasia, thickening of the subendothelial layer, proliferation of the cellular elements of adventition, and growth of argirophylic fibricity within it. Point hemorrhages in various stages of dissolution are noted in almost half the cases of traumatic neuritis.

With breaks and degeneration of the nerve fibers, schwann and axiocylindrical growths are almost continuout in the cases of traumatic neuritis. As a rule, they are not very intensive and are always subject to distrophic changes. Interfascicular neuromas and diffuse axiocylindrical growths with distrophic changes are an almost constant component in the histopathological picture of traumatic neuritis after a sustained trauma without injury to the epineurium.

The question arises, what is traumatic neuritis? Is this an independent inflammation or is it a secondary reaction to local tissue destruction or hemorrhaging? Speaking in favor of the independence of the inflammatory process and its independence from tissue disintegration and hemorrhages are: 1) the cellular composition of the infiltrates, which contain plasmatic cells and leukocytes; 2) the duration of the inflammatory process, which does not weaken as the area of injury becomes clear of products of decomposition and extravasate, but may persist for a long time after the completion of organization of the tissue defect.

Intra-trunk cicatrices with residual conditions after traumas to the peripheral nerve trunk and without injury to the epineurium are characterized by more or less strong connective tissue growths without accompanying inflammatory changes and without the presence /67 of extravasate. These are primarily residual conditions after intra-trunk tissue breaks, which are very common with contusions, commotions and strains of the nerves, and which are quite rarely the object of surgical intervention. Secondly, these are residual conditions after trauma to the nerve trunk without injury to the epineurium, with multiple hemorrhages, long-term inflamation and introduction of foriegn bodies. Intra-trunk cicatrices of the latter origin are more massive and rougher than those of the former, and therefore they are often the object of operative excision.

Connective tissue growths are usually of a diffuse character and are expressed by non-uniform thickening of the peri-, endo- and epineurium. In growths which are not accompanied by hemorrhages, inflammation and the introduction of foreign bodies, the connective tissue fascicles are looser and more regularly oriented parallel to the length of the nerve trunk. Aside from this, the breaks in the nerve fiber fascicles are always evident, sometimes on the entire cross-section of the nerve trunk with the formation or either an inter-fascicular neuroma or an intra-trunk neuroma, or with diffuse penetration of schwann-axiocylindrical growths of hypertrophized connective tissue framework of the nerve trunk.

Degenerative changes in expanded connective tissue are frequent along the type of homogenization and hyalinization of fascicles of collagen fibers with their globular disintegration and with distrophic changes in the hyperplastic schwann cells and regenerating axial cylinders.

Intra-trunk scar formation is often accompanied by changes in the vessels with endothelial hyperplasia.

Inclusion of the nerve trunk into the cicatrix

This is the last form of residual condition, which is very important in a neurosurgical respect. More precisely, it is a special form of trauma of the nerve trunk, expressed in its compression by the scar.

The dense cicatrical tissue encircles the nerve trunk on all sides, lacing and compressing it. The nerve trunk here is thickened, greyish-white in color, and sometimes hyperemiated. Above and below the scar constriction on the nerve trunk there are usually small swellings.

The inclusion of the nerve trunk into the scar in connection with injury to the bone is unique. There are cases when the entire nerve trunk is included into the bone callous. Sometimes part of the nerve lies within the callous, while the other part is pressed to it with soft tissue. Cases of the fusion of the nerve trunk with the vascular walls are not rare.

Under microscopic study, the nerve fiber fascicles are narrowed, the nerve fibers are disintegrated, and the axial cylinders are atrophied. In the peripheral segment of the nerve which is included in the scar there are sometimes manifestations of Waller degeneration.

The cicatrical tissue which is removed with neurolysis of the compressed nerve is very often characterized by a sharply expressed hyalinization of the collagen fiber fascicles and by growth of the thick-walled vessels, sometimes with wasting of their opening. Neurotization of the scar tissue is often expressed. Its sources are the thin nerves, muscular, cutaneous and vascular stems, sometimes with the formation of rather large neuromas according to the central type.

## CHAPTER IV

## REGENERATION OF NERVE TRUNKS AFTER FIREARMS WOUNDS

### General problems of regeneration of peripheral nerves /68

The process of regeneration of the peripheral nerve after it has been wounded is closely tied with the process of degeneration. Already at the end of the XVIII century there were indications that a severed nerve loses its conductivity and that regeneration may occur after severance. In 1851, Waller demonstrated on an extended frog's tongue that after the hypoglossal nerve is severed from the center, the segment of nerve fibers is subjected for its entire extent to degeneration and that regeneration takes place by means of nerve fibers growing out of the central segment, growing through the cicatrix, and moving along the peripheral segment through the degenerated fibers. Waller first described the process of fragmentation of nerve fibers of the peripheral segment with their degeneration and at the same time indicated that in regeneration, the newly formed nerve fibers differ sharply in their appearance and smaller caliber from the fibers of the central segment.

By the end of the last century, two basic viewpoints prevailed concerning the process of regeneration of a nerve after its severance: 1) according to the monogenetic viewpoint, or the growth theory, the regeneration of a nerve subject to degeneration takes place by means of branches growing out of the central segment axons which are directly connected with the nerve cells, without the significant participation of schwann cells; 2) according to the polygenetic viewpoint, new axial cylinders originate from the schwann cells of the peripheral segment and central stump, which multiply rapidly during the degeneration process; thus, the schwann cells were credited with neuroblastic properties and regeneration was considered to be autogenic.

Recently there has been observed a certain convergence between the two indicated viewpoints, which present the complex process of nerve regeneration in a unilateral schematic and simplified form, although even now there are still significant principle differences.

Practically important is the generally accepted position that for restoration of function in connection with nerve regeneration, the presence of schwann cells in the peripheral segment and their continuous connection with the central segment is just as important as the preservation of the nerve center with the central segment of the nerve.

At the present time we may consider the fact established that the schwann cells are a peripheral neuroglia, co-travellers or satellites of the nerve fibers, which have a very close relationship to the processes of their metabolism. The pulpous membrane is formed/69 only with the presence of schwann cells. Mature nerve cells which are not associated with schwann cells are non-viable. New experimental studies with the cultivation of schwann cells outside the organism performed by N. G. Khlopin led him to the conclusion that "schwann cells represent unique histologically determined elements of peripheral neuroglia, which under conditions of tissue cultures do not ascertain the capacity for progressive conversion into tissue elements of another origin".

For a better understanding of the changes which lie at the basis of various forms of human nerve trunk injuries, it is necessary to be acquainted with the normal structure of the nerve trunks and with their histopathology, particularly with the basics of the nerve degeneration and regeneration processes.

The nerve fibers of the peripheral nerve trunks are related to pulpous and non-pulpous. Nerve trunks of the extremities, with the exception of the cutaneous branches, are mixed nerves, i.e., containing motor, sensory and vegetative fibers. This is true also for

muscular branches which contain, aside from motor and vegetative fibers, sensory conductors (for deep pain and proprioceptive sensitivity), and even for the anterior roots and cranial motor nerves, which contain a certain amount of sensory fibers. Motor fibers have the largest caliber. Sensory conductors for the most part have medium- and small caliber fibers. Non-pulpous fibers, evidently, are excclusively post-ganglion vegetative conductors.

Each pulpous nerve fiber contains an axial cylinder, which is an offshoot of the nerve cell and consists of water-rich axoplasm and neurofibrills submerged in it. In pulpous fibers the axial cylinder is covered with a pulpous membrane, as a casing, which is interrupted only in the area of the Ranvier's crosses and absent in the initial section of the nerve fiber upon its exit from the body of the nerve cell, as well as in the terminal section before the formation of the nerve ending. The schwann cells, which form a very thin membrane of the nerve fiber, in pulpous fibers are located in single-file in the center of each interannular segment and are most closely tied anatomically and physiologically with nerve parenchyma, i.e., with the pulpous membrane and the axial cylinder. Genetically, schwann cells are derivative elements of the primary medullary tube and homologues of neuroglia of the central nervous system, being a specially differentiated peripheral neuroglia of extodermal origin. In mature pulpous fibers, schwann cells are represented by large, heavily elongated elements of star-shaped form (fig. 21). Their nucleus with an accumulation of protoplasm surrounding it is located in the center of the interannular segment, and their shoots, which seem to be extended according to the cylindrical form of the fiber, stretch along the entire extent of the segment. The longest longitudinal shoots in the area of the Ranvier's crosses are tied with the thin shoots of the schwann cells from neighboring segments, thereby forming a continuous plasmatic syncytium. The pulpous membrane myelin is a product of the axial cylinder and the schwann cells. In mature pulpous fibers, the entire thickness of the pulpous membrane is

permeated with such protoplasmatic threads of schwann cells. The so-called schwann membrane is a thin webbing formed by the ectoplasm of the schwann cells on the outside surface of the nerve trunk and separating it from the surrounding endoneural lymphatic crevices./70 Thus, it is a marginal membrane separating the ectodermal nerve parenchyma from the surrounding mesodermal tissue. Morphologically as well as functionally, the schwann cell is most closely tied with the nerve fiber (fig. 22): achieved through its mediation is the metabolism of the fiber, products of metabolism and decomposition in the form of various intra-cellular inclusions -- $\Pi$ -granules (fig. 23), Elzholz bodies are deposited in its protoplasm. With degenerative processes in the nerve trunk, the schwann cell undergoes clear reactive changes and therefore may serve as an indicator of the condition of the nerve fiber. It is an adequate growth medium for the nerve fiber, and without its presence the mature nerve fiber is non-viable.

The axial cylinders of non-pulpous fibers are encased in the protoplasm of schwann cells, which form syncytial crossings along the course of the nerve trunk. Passing through the schwann syncytium of a single fiber are several axial cylinders which form a unique cable. The axial cylinders merge into neighboring fibers along the anastomoses of the schwann syncytium, thereby forming an interweaving of the cable systems which represents the non-pulpous fibers of the nerve trunk (B. I. Lavrent'yev, Nazhott et al.).

The nerve fibers form within the nerve trunk a series of individual fascicles of various size. Each fascicle is surrounded by a dense elastic connective tissue membrane consisting of several concentric layers of laminar tissue -- the so-called perineurium. Running from the inside surface of this perineural membrane are connective septa within the fascicle. Connected with them in turn are thin connective tissue interlayers between the individual nerve fibers.

This connective tissue stroma which laminates the inside of each fascicle and surrounds each nerve pulpous fiber and group os non-pulpous nerve fibers is called the endoneurium. The nerve fascicles are separated from one another by a loose fatty tissue which surrounds the entire totality of the fascicles and connects them to the nerve trunk. Passing through this external membrane, called the epineurium, which is the soft fatty nerve cushion, are large blood vessels whose smaller branches penetrate into the inner nerve membranes. While the epineurium has true lymphatic vessels, the perineurium and endoneurium are provided with lymphatic crevices (fig. 24).

The nerve fascicles which are enclosed in the perineural membrane do not run isolated from one another in the form of cables for the entire length of the nerve trunk, but rather form a complex intra-trunk plexus. According to the course of this plexus and the perineural tube they sometimes diverge, sometimes merge or are joined together by smaller tubes. Therefore, in a series of cross-cuts, the number, size and location of fascicles in the nerve trunk are extremely variable.

In order to characterize the difference in the internal structure of the nerve trunks of extremities in various small animals, in large mammals, and in man, we may present the following data in the way of an example. In the frog the nerve trunks of the anterior and posterior extremities consist of one fascicle of nerve fibers encased in a single common perineurial membrane. In mice the sciatic nerve contains 1-2 fascicles, in rats -- 2-3 fascicles. Among the small animals studied, only in the guinea pig was the number of fascicles encased in individual perineural membranes significantly greater. In the rabbit the number of fascicles in the more proximal sections is also small, and increases in the distal sections. However, in /71 large mammals the number of fascicles in the nerve trunks of the extremities is extremely great. Thus, in the pig the sciatic nerve at the level of the central third of the femur contains 82 fascicles, the median nerve in the shoulder -- 33 fascicles, in the foreleg -- 13. In the ulnar nerve on the shoulder there are 36 fascicles, and

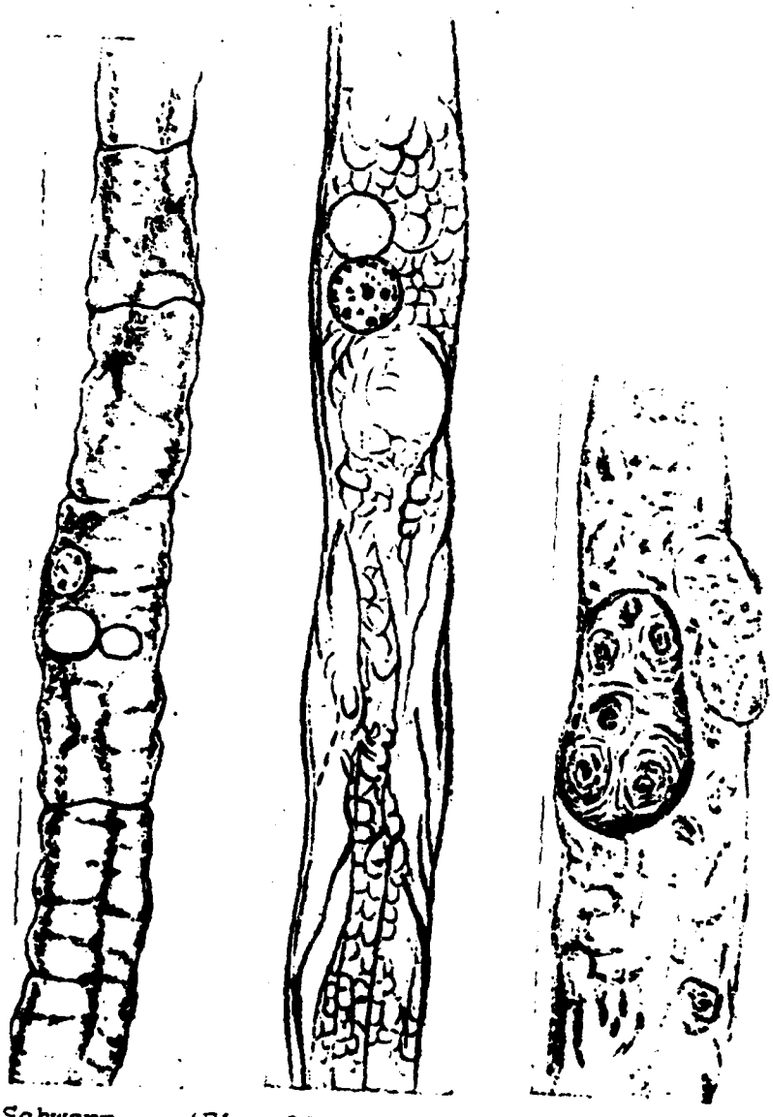


Fig. 21. Schwann cell of nerve pulpous fiber from the sciatic nerve of a rabbit. Stained with hematoxylin

Fig. 22. Schwann cell of nerve pulpous fiber from the root of a human cauda equina. Its protoplasm has very close connection with the axial cylinder and myelin. Stain according to Doynikov.

Fig. 23. Collection of P-granules in the protoplasm of a schwann cell in the root of the cauda equina of an 80-year old man. Stain according to Nissl.

in the radial on the shoulder -- 49. In the horse the number of fascicles in the sciatic nerve reaches 146 (at the level of the central third of the femur), and the tibial part of the nerve trunk is separated from the fibular by a thicker layer of internal epineurium than the individual fascicles of one and the other part of the nerve trunk.

In humans in the mixed nerve trunks of the extremities, the number of fascicles forming a complex plexus is rather significantly subjected to individual fluctuations and changes at various levels. In the sciatic nerve in the buttocks region the number of fascicles is equal to 70, at the level of the central third of the femur -- 54; the tibial nerve near the point of division of the sciatic nerve has 45 fascicles, the interior plantar nerve -- 24 fascicles, the exterior-- 23 fascicles. In the distal regions of the extremities -- in the hand and foot -- the number of fascicles in the individual branches of the corresponding branches is rather significant, despite the small caliber of these branches. Thus, for example, the ulnar nerve in the armpit contains 8 fascicles, in the elbow region -- 7; the surface branch of this nerve on the hand contains 17 fascicles, the deep branch -- 7; the branch in the muscle moving the thumb contains 7 fascicles, and in the interosteal muscle --4—3 fascicles (fig. 25).

## Degeneration of the nerve fibers

With traumatic injuries to the nerve trunks, three regions may be separated along their expanse: 1) the traumatic zone, i.e., the directly injured area; 2) the peripheral segment of the nerve trunk; 3) the central segment of the nerve trunk.

1. The traumatic zone. In this zone with the slightest injuries, for example, with contusion of the nerve, the pathomorphological changes of its component elements may be expressed in varying degree. The most vulnerable are the nerve fibers. With light traumas there may be only local changes in the myelin membranes (periaxonal degenerative process), or the axons may be severed in varying degree with subsequent Waller degeneration of their peripheral segments. The

most stable are the elements of connective tissue membranes of the nerve trunk, but even these may be subjected to breaks with extensive intra-trunk hemorrhaging and formation of necrotic areas.

With firearms wounds, partial or complete anatomical severance of the nerve trunk is quite common with more or less extensive necrotic changes in the nerve fibers with their schwann cells and connective tissue membranes with their vascular network. Hemorrhaging in the region of the traumatic zone in the external or internal connective tissue membranes, introduction of foreign bodies -- these are a common occurrance. Infection of the wound, often with the extensive formation of scars around and inside the nerve trunk, may sharply disrupt the intra-trunk structure of the nerves and hinder the neurotization of the peripheral segment of the nerve.

2. The peripheral segment of the nerve trunk. The process of Waller degeneration develops along the extent of the peripheral nerve segment.

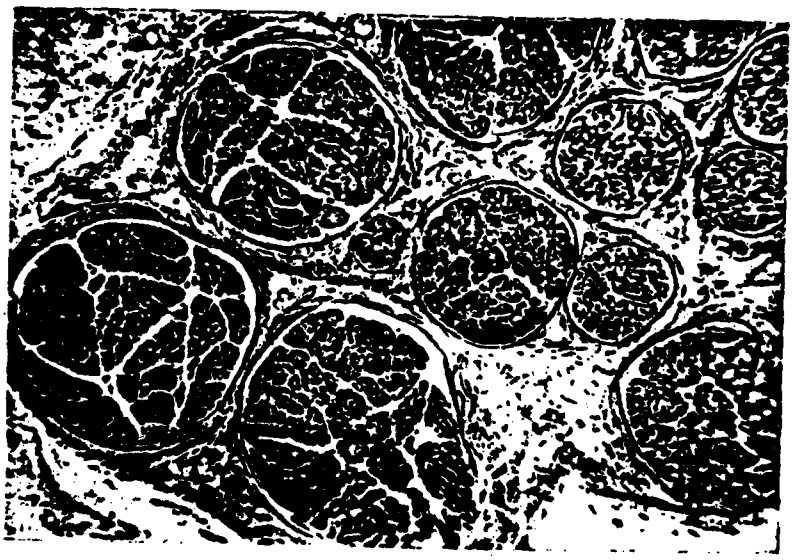


Fig. 24. Cross-section of a human sciatic nerve. Structure of the nerve trunk. Stain according to Veygert.

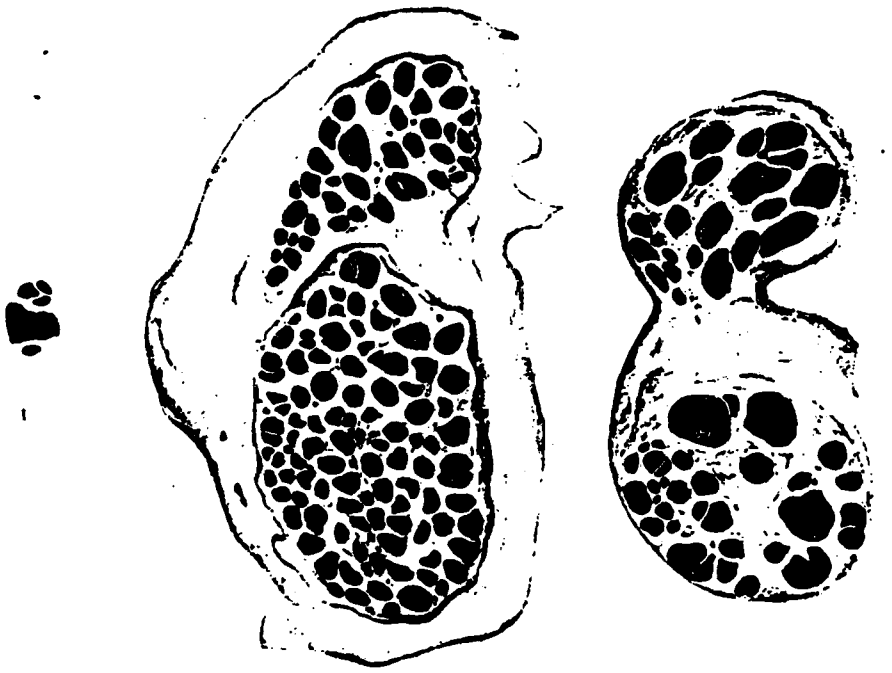


Fig. 25.
1 - cross-section of the sciatic nerve of a rabbit at the level of the central third of the femur;

2 - cross-section of the sciatic nerve of a horse at the level of the central third of the femur;

3 - cross-section of a human sciatic nerve at the level of the central third of the femur.

Stain according to Veygert.

At the present time it has been firmly established that with /72 the disruption of the continuity of a nerve, a disintegration of the axial cylinders and pulpous membrane occurs in the distal segment removed from the center.

Degenerative changes do not occur simultaneously in the individual nerve fibers. In the thick pulpous nerve fibers the beginning of disintegration is noted earlier than in the thin ones, with non-pulpous fibers being particularly resistant. Changes in the axial cylinders are primary, and myelin changes occur later. In some axial cylinders the changes are found by the end of the first day, and specifically changes in their caliber, coloration, fibricity of neurofibrills. In the following days there is a disintegration of the axial cylinders into long pieces, and subsequently granular disintegration and complete dissolution. In some pulpous fibers the first visible changes which set in within 24 hrs. after the nerve is severed have the appearance of gradually deepening depressions on the surface of the fiber. These depressions lead to the disintegration of the fiber into individual globules of elongated-oval shape, which surround the axial cylinders. In all probability, the individual fibers are afflicted simultaneously along their entire extent, since on the motor terminal end plates there are clearly visible degenerative changes by the end of the first day of severance.

With secondary degeneration, the axial cylinders and the pulpous membranes are subjected to deep physico-chemical changes and, finally, completely disintegrate. Participating in this process of destruction of the pulpous fiber are not only the schwann cells, but also various mesodermal elements of the endo- and perineurium.

With disintegration of the non-pulpous fibers, the leading role belongs to the schwann cells.

Approximately 48 hours after the nerve is severed, obvious reactive-progressive changes are apparent in the schwann cells of numerous nerve fibers. By about the 5-th day it is possible to note the first cariokinetic division of nuclei of the schwann cells. The proliferation of schwann cells gradually grows in the subsequent days and continues with decreasing intensity to the end of the 3-rd week. Division of the nuclei is not accompanied by the division of the cell body, as a result of which the protoplasm of the schwann cells forms

continuous bands of cellular chains, which represent the beginning of the formation of Bungner bands (fig. 26).

The schwann cells manifest a viable phagocytic activity: they surround the pulpous globes with the included fragments of axial cylinders with their plasma. These axial cylinders, having disintegrated into globules, in most cases dissolve and are absorbed within the course of the first week. Only individual rounded residues of the axial cylinders remain for a long time within the pulpous globes. The pulp of the disintegrated pulpous fibers which is enclosed in the schwann cell plasma undergoes, as we have already mentioned, deep physico-chemical changes, which may be observed with staining by various chemical methods. The Marki method gives an exceptionally bright picture of the gradual splitting of the myelin: the pulpous globes are stained partially and fully in a brown color, approaching black. The action of osmic acid on the disintegrating myelin is evidently explained by the splitting of the fatty acids during myelin disintegration.

The process of darkening of the pulpous globes with the use of the Marki method lasts for 3-4 weeks. This stage of degeneration may be called the Marki stage.

/73

As the amount of blackening myelin increases in Marki preparations, its amount in preparations stained with hematoxylin according to Veygert is reduced. The result of the phagocytic activity of the schwann cells is the gradual accumulation of lipoid droplets within them, which are stained bright red by sudan III and scarlet and subsequently yield a reaction on the fatty acids and neutral fats (B. S. Doynikov, A. V. Rakhmanov, L. I. Smirnov).

Occurring simultaneously with the changes in the schwann cells in the initial stage of degeneration are also the reactive changes on the part of the mesodermal elements of the endoneurium. First of all in the endoneural tissue between the nerve fibers there appear small

Fig. 26. Divided schwann cell forming a cellular chain, from the tibial nerve of a rabbit on the 5-th day after severance. Stained with polychromic methylene blue.

Fig. 27. Ovoid distention at the point of a disintegrated section of pulpous fiber, formed by macrophages entering the schwann cell. The tibial nerve of a rabbit on the 15-th day after severance. Stained with iron hematoxylin

cells -- polyblasts, which have ameboid mobility and a slightly developed protoplasmatic body.

Similar cells originate partially from mature Maximov's dormant wandering cells, partially -- from emigrated lymphocytes. From day to day these cells progressively develop, take on multiple characteristic forms, and manifest their viable phagocytic activity. In the middle of the first week it is possible to observe singular accumulations of polyblasts on the surface of the denerated fiber. Subsequently there is a partial introduction or ingrowth of these elements into the accumulations of myelin globules. Their rapidly growing protoplasmatic body takes on a foamy, grated or cellular structure and soon permeates the myelin globules, which is particularly apparent in split preparations or cross-sections. The tuberous nuclei which are often rich in chromatin penetrate from the surface into the center of the pulpous globes. The introduced polyblasts grow among the pulpous globules, increase in number by means of mitotic division, and turn into typical macrophages. They develop a viable phagocytic activity, break up the myelin, and gradually accumulate an increasing amount of fat in their vacuoles. The macrophages are nested primarily in the pulpous globes of thick-caliber nerve fibers, whose splitting takes place much more slowly than that of thin-calibered fibers, and are like additional phagocytes. In the thin-calibered pulpous fibers and in the non-pulpous fibers, in which the processes of disintegration develop more rapidly, the myelin and the disintegrated axial cylinders are phagocytized only by the schwann cells (B. S. Doynikov).

The immobile elements of the endoneurium, and after them also the perineurium, are drawn into the process of disintegration: the fibroblasts of the endoneurium soon begin to grow and gradually accumulate fat in their cell body in the form of thin droplets. Soon the first drops of fat appear also in the protoplasm of the perineurium cells. In the course of the next few weeks, the processes of disintegration continue. The macrophages, overloaded with residues of myelin and fatty substances, collect along the course of the degenerated nerve fiber, here and there in large oval clumps. As a result of this,

distentions are formed in the area of the disintegrated section of fiber, which is replaced by a chain of schwann cells (fig. 27). In the later stages of degeneration, the macrophages in the ovoid distentions, along with the fats, contain cholinesterase in a considerable quantity, i.e., a mixture of cholesterol with fatty acids (B. S. Doynikov). The fatty substances which gradually accumulate by the end of the first month condition the histological picture which may now be designated at the scarlet stage. The elements of the endo- and perineurium contain large amounts of fat which has collected in the mobile, rounded cells, starting from the small polyblasts to the large macrophages, as well as in the greatly enlarged immobile /74
elements -- the fibroblasts and the endothelial-like cells of the perineurium. The macrophages which have collected in the form of oval distentions gradually begin to free themselves from the plasmatic syncytium of the schwann cell chains and to penetrate into the endoneural crevices through the damaged schwann membrane, where they may be seen over a period of months. Sometimes they collect in the form of large accumulations in the adventitial spaces of the endoneurial vessels.

Subsequently the syncytial cellular chains gradually free themselves of the products of decomposition, and in the mesodermal tissue of both internal nerve membranes there accumulates a growing amount of fatty products.

In the endoneurium the macrophages collect primarily around the vessels in the form of jackets. Moreover, in the endoneurial tissue there are everywhere dispersed small accumulations and individual macrophages. Gradually the small fat drops collect in ever greater numbers in the cells of the perineurium. The purification processes in the thick nerve trunks occur in the same way as disintegration processes, considerably slower than in the thin nerve trunks. In the non-pulpous terminal sections and ends of the pulpous fibers, the disintegration and purification take place over a period of several days.

In humans, the fat which is deposited in the connective tissue membranes gradually disappears in the larger volume nerve trunks, but the purification process may sometimes last for many months.

3. The central segment of the nerve trunk. The nerve fibers in the central segment of a severed nerve do not remain totally invulnerable. Here the changes affect only individual nerve fibers, and their intensity changes depending on the severity of the trauma. By their nature, these changes are completely different from secondary Waller degeneration. The primary acute changes in the fibers, which begin very early, touch upon the axial cylinders. There appear spindle-shaped and globular distensions and loosening of the neurofibrills which follow one another and ascent toward the center from the point of severance for varying distances. Acute changes in the axial cylinder develop simultaneously with reversible changes in the nerve cell of which it is an offshoot and, like the latter, they have the capacity for regeneration.

The chronic, gradually developing degenerative process leads to the atrophy of the corresponding nerve fibers and testifies to segmental periaxonal changes in the pulpous fibers. Visible in the nerve fibers affected by this process is a collection of Elzholz bodies, similar to the gradually developing degenerative changes seen in toxic neuritis. The accumulation of Elzholz bodies, which may serve as an indicator of the atrophic processes taking place in the pulpous fibers, changes in connection with the intensity of the degenerative processes and is an early stage of decomposition of the pulpous fibers. With further disintegration there is noted an appearance of fatty substances in the schwann cell protoplasm and in the membranes, while the number of Elzholz bodies diminishes and the pulpous fibers become thinner. Thus, sections with atrophied pulpous membrane alternating with less changed segments are visible along the course of the nerve fibers. This process is closely associated with the atrophy or reversible changes in the nerve cells of the corresponding nuclei of grey substance, whose offshoots are axial cylinders of the damaged nerve trunk.

## Regeneration of nerve fibers

The regeneration of nerve trunks is a very complicated process /75 in which elements of various tissues participate in a certain interaction. The axial cylinders, schwann cells, connective tissue membrane cells, tissues and organs where the nerve fibers terminate all take part in the restoration of the disrupted nerve trunk function.

In just a few hours after damage to the nerve there develop reactive changes, partially degenerative and partially initial regenerative, in the remaining viable nerve fibers of the central end, which are clearly divided from the necrotic zones and form the so-called metamorphic zone (Kakhal). These initial regenerative phenomena develop rapidly in the course of the next few days. The retained fibers usually swell, their fibrillar framework becomes splits. Often the fibrill fascicles grow out of the split axial cylinder, terminating in end stumps (fig. 28). Deserving of particular attention is the fact that the new branches of nerve fibers which develop in the protoplasm of the schwann cells, continue at first to grow inside the old schwann cells, but very soon there are found oblique, laterally distended, and sometimes reverse-directed lateral branches (fig. 28) which grow freely or break through the connective tissue. Individual fibrills supplied with end nodules penetrate into the blood clots of the injured zone. Such early branches of the axial cylinders in most cases are soon subjected to the process of degeneration, while slightly above the nerve stump the axial cylinders give new lateral branchings. It is interesting that on the dull end of the peripheral segment in some nerve fibers, and specifically in the non-pulpous, there is observed a loosening of the neurofibrills with the formation of thin lateral branches supplied by end nodules, which soon degenerate. The neuroplasm of the nerve fibers separated from the nuclear part of the nerve cell is capable for a short time, before the onset of necrobiosis, of a reaction which indicated the abortive regenerative changes very similar to the corresponding processes in the central stump.

At the same time in the area of the nerve severance there develop reactive inflammatory processes, in the necrotized tissue and hemorrhages there is a process of purification and, finally, a scar is formed which consists of connective tissue cells and fibers. Taking part in this process are the rapidly growing connective tissue elements of nerve trunk membranes, which form the scar between both stumps of the damaged nerve.

An important significance in the neurotization of the scar belongs to the growth of the schwann cell chains, which takes place primarily from the ends of the nerve fibers of the central stump, as well as from the peripheral, particularly with major defects in the nerve. This viable proliferation begins early in the area of the schwann cell chains, which penetrate from the nerve stumps into the area of injury and form irregular passages there. The schwann cell chains which grow out of both nerve stumps join together if there are no insurpassable obstacles in their way, and form a continuous syncytial plexus.

It is difficult to say whether or not there are any chemical factors which influence this process. However, it is clear that the direction of the above-mentioned cellular chains depends on the structure of the scar tissue. The greater the defect in the nerve, the more numerous are the cellular chains which stretch randomly along the /76 longitudinal axis of the nerve in all directions, and even backwards.

The young axial cylinders grow out of the old axial cylinders and stretch to the area of traumatic distruction primarily inside the protoplasm of the old schwann bands. With further injury in the area of affliction, these cylinders locate themselves in the protoplasm of the accompanying schwann cells, and do not grow, as "free axial cylinders" in the scar tissue. In these early stages, there are often found plexuses and spiral whorls around the old axial cylinders which are formed from the abundantly growing branched young axons ending in numerous terminal nodules. These early-developing spirals, and sometimes the reverse-directed fibers, are the first condition for the

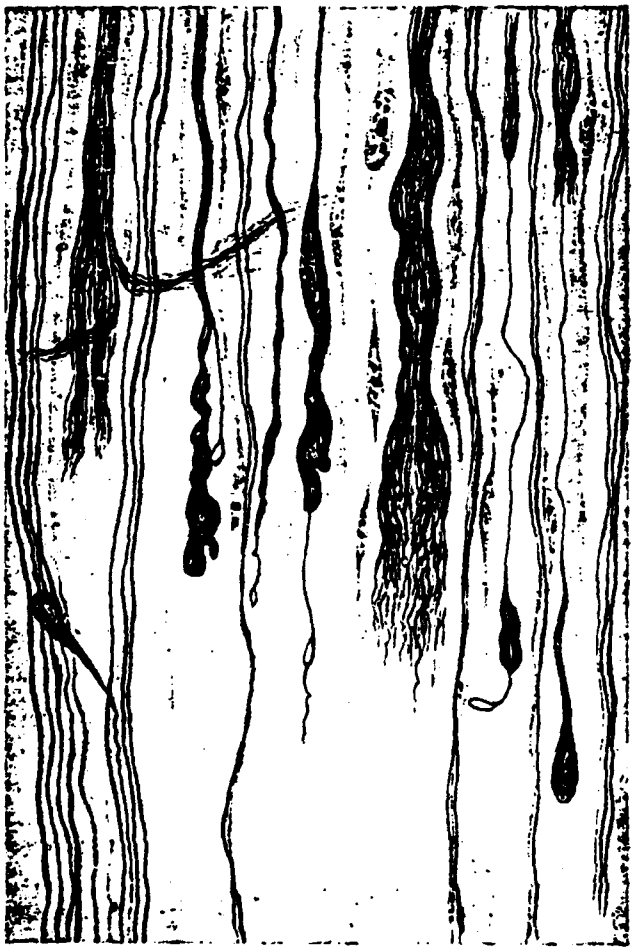


Fig. 28. First signs of regeneration in a human sciatic nerve 3 days after injury. Impregnation with silver according to Kakhill.

formation (particularly in the period of the 2-nd to the 4-th week) of tangled clumps and balls of axial cylinders (fig. 29) known under the name of Perronchito spirals, which sometimes may be observed in old neuromas (fig. 30). The emergence of these spirals, which are usually

noted on the boundary of the central stump and the scar tissue, is explained by the presence of obstacles during their growth. Speaking in favor of this explanation is the fact that typical, well expressed Perronchito spirals develop only with traumatic injury to the nerve. On the other hand, it is impossible to overlook the fact that rudimentary clumps of fibers are observed in regenerating nerve fibers during degenerative processes of non-traumatic origin, as for example during neuritises. [It is also impossible to overlook the fact that] the clumps form shoots of sensory nerve cells of spiral nodes and nerve fibers which encircle the bodies of the sensory cells and form neuro-muscular spindles and various encased terminal apparata. All this points to the fact that the young nerve fibers may form clumps in the area of the terminal branches in connection with the presence of obstacles for their further forward progress.

If the above-described relationships between the growing axial cylinder and the schwann syncytium are regular, then we should note that there are numerous deviations during these processes, particularly in the early stages. We are speaking of isolated axial cylinders which form small groups and which are often distinguished by their unique winding paths which do not correspond with the longitudinal course of the schwann cell bands in the young scar tissue. With superficial observation, it is impossible to see the nuclei which adjoin these axons. In the first days after the nerve is severed, branches are found in the central stump which grow laterally from the trunk, crossing obliquely with numerous neighboring nerve fibers, and after repeated division forming endings of various forms.

Upon analyzing the phenomena taking place in the central stump in the early stages, it becomes clear that several hours after the nerve damage, the growth of axial cylinders begins, with the emergence of lateral branches and with a tendency toward spiral formations. At the same time, there are no progressive changes noted yet in the schwann cells.

The movement of the young nerve branches into the scar tissue, which is usually observed in the subsequent days, takes place most often with the simultaneous progress of the schwann cell chains, with the young axial cylinders seemingly included in their protoplasm and sometimes bounded by the nuclei of the schwann cells. The progress of the schwann cell chains and the nerve branches may occur at separate times: often one process lags behind the other. The development /77 of Perronchito spirals in the scar tissue in the early stages, which is rightly called the hindrance phenomenon, may be explained by the delay in the growth of schwann cell chains. On the other hand, schwann cell chains which are devoid of axial cylinders are an example of delay in the growth of the branches of old axial cylinders. The movement of free branches of axial cylinders along the obliquely stretching collateral branches is especially clearly expressed in the first days after the nerve injury (fig. 28). The conclusion that the schwann cell chains "catch up with" the young progressing branch may be drawn in this case by comparing the pictures where we see first the outlined development, and then the well developed Perronchito spirals. While the nuclei of the longitudinally bent axial cylinders are not visible in the young spirals, in the old spirals which have reached their full development there are uniformly distributed cell nuclei in the fiber whorls. Individual spirals remain in the old neuromas as constant formations and become overgrown with pulpous covering.

The above-mentioned observations and ideas indicate that the regeneration process is essentially a growth process on the part of the axial cylinder, and that a necessary adequate medium for it is the syncytium of the schwann cells.

The axial cylinders in the scar tissue which grow out of the central stump in the schwann cell chains are often branched. Since one nerve fiber from the central stump usually forms many shoots, which in turn are once again divided in the scar tissue, as a result there is a huge number of nerve fibers in the scar tissue. The newly formed fibers are usually directed lengthwise and crosswise to the schwann cell chains, meet vessels along their path, stretch along their adventitions, permeate into the epineurial fatty tissue, wind around the fat cells and form numerous branches supplied with terminal heads

Fig. 29. Perronchito spiral 4 weeks after injury to a human sciatic nerve. Impregnation with silver according to Kakhal.

Fig. 30. Perronchito spiral in a 10-year old neuroma in a human median nerve. Impregnation with silver according to Kakhal.

(fig. 31). Such branches supplied with terminal heads are formed when the fiber meets an insurmountable obstacle in the scar in the form of rough connective tissue, foreign bodies, etc. In individual cases such terminal formations may be exceptionally large (fig. 32).

The newly formed fibers take a complex route in the scar tissue: they deviate away from the foreign bodies which lie in their path, often they stretch across the scar and grow into the surrounding tissue or turn back to the central stump, forming tangled plexuses and spirals around its perineurium. Only near the peripheral stump do the newly formed fibers stretch in a longitudinal direction and finally reach the schwann cell chains of the peripheral stump where, ordered in the plasmatic bands, they continue their course.

The neurotization of schwann plasmatic chains of the peripheral segment develops rapidly. The young shoots of axial cylinders neurotize the schwann cell chains in fascicles. Deserving particular attention is the fact that in the progressing axial cylinders it is rarely possible to see terminal formations. Terminal thickening, rings, etc. are formed upon encountering obstacles during growth, as for example, products of decomposition of old fibers. This unclear delineation of the terminal sections of axial cylinders moving in the schwann syncytium of the peripheral end, illustrates the fact that the latter represents an adequate medium for the axial cylinder shoots growing out of the central stump, and that it is in close /78 and indivisible anatomical and physiological contact with neuritis, as is the case in normal maturing nerve fibers.

All newly formed nerve fibers are first non-pulpous. The pulpous membrane, in whose construction participate the axial cylinder as well as the schwann cells, is formed somewhat later. The maturity of the nerve fiber is determined not only by the presence of the pulpous membrane, but also by its corresponding thickness and structure, characterizing fibers of different caliber.

77a

/77a

Fig. 31. The growth of regenerating fibers in the fatty tissue of the epineurium. Impregnation with silver according to Kakhal.

/77b

Fig. 32. Complex nerve endings in the scar tissue of an old neuroma. Impregnation with silver according to Kakhal.

Particular mention must be made of processes which are observed /78 with the neurotization of the peripheral terminal apparata, which has a decisive significance for the restoration of functions. Complex coordinated processes develop in the schwann cells of the terminal nerve branches as well as in the connective tissue and in the cellular elements of the terminal organs.

In the motor terminal branches, the nerve fibrills swell up at the ends, divide dichotomically, and sometimes bend backwards. The schwann cell chains do not remain passive -- they now grow in different directions and connect, evidently, with the aid of thin protoplasmic continuations with sarcolemma. As a result, new connections are formed with the muscular fibers and it becomes possible to have closer contact between the growing nerve fibers and various muscular fibers. The nerve fibers, traveling inside these plasma tubes, penetrate through the sarcolemma into the sarcoplasma of the motor end plates in the form of split neurofibrills which form lateral branches covered with terminal loops or terminal branches.

These newly formed terminal organs differ primarily by their excessive number of lateral branches, which often have a strange form. Often the individual young fibrills, after formation of the motor end plate, may be directed to other muscular fibers. Several months after restoration of the nerve function, there is a gradual change in the restored motor end plates. The complex atypical end formations with their numerous strange branchings gradually disappear, new end branches are formed, and within several months the end plates take on a normal shape. The regeneration of the receptor terminal apparata also takes place in a similar manner. Here the growing nerve fibers move forward inside the schwann cell plasma, reach the tactile cells, branch around them inside the plasma of the capsul cells, penetrate between the tactile cells, and form here the neurofibrillar framework of the nerve disk. In this case also the normal shape of the nerve endings is restored in only a few months.

All the above-mentioned regeneration processes decisively speak in favor of the monogenetic viewpoint, but not in its initial dogmatic

form, which does not correspond with the modern views on the close interconnections between the cellular elements of the living organism. These viewpoints do not contradict the principles of nerve study, which in the course of time has also been subjected to certain changes and rightly retains its significance even today. It is impossible to agree with the polygenetic viewpoint (Byungner, Bete, Dyurk, Shpil'-meyer, Buke and others), according to which the schwann cell exhibits axoblastic properties in the presence of central irritation and the /79 peripheral nerve fibers have a multi-cellular origin during regeneration. The study of early regeneration stages, particularly in the simple structured nerve trunks of small mammals, and the observation of processes of restoration of terminal endings speak out against this viewpoint.

## Heterogenic regeneration

The old question of the fusion of motor nerve fibers to receptor nerve fibers, which has long interested physiologists and anatomists and was interpreted differently, has recently received much illumination in the works of B. I. Lavrent'yev, P. K. Anokhin, Buke and others.

In tests performed on animals in which with the severance of the hypoglossal and lingual nerve there was alternate connection of the central stump of the hypoglossal nerve with the peripheral segment of the lingual or, on the contrary, the central stump of the lingual nerve with the peripheral segment of the hypoglossal, Buke was able to establish that in general the regeneration processes in the central stump, in the scar tissue and in the old fascicles of the peripheral segment develop regularly. The motor vibers grow into the sensory paths and vice verse and, as we know, once the regenerating nerve fibers get into the nerve paths of the peripheral segment, they proceed along inside these old nerve paths to their termination.

Deserving particular attention are the regeneration processes in the terminal region and the formation of terminal formations. When the young fibers which have grown out of the hypoglossal nerve reach the terminal region of the lingual nerve, their growth continues in the connective tissue of the tongue mucous membrane. Arising in the

area of the terminal branches are random plexuses with formation of intraplasmic terminal branches or terminal loops, which are only an imitation of the corresponding structures of normal sensory fiber endings of the tongue. Sometimes terminal branchings are encountered which are reminiscent of motor end plates. Part of the regenerating nerve fibers penetrates even into the epithelium, in whose deep layers they often form terminal branches. Another part of them ascents to the upper cellular layers and there terminates in the form of rings on the ends of the branches. And nevertheless with heterogeneous regeneration there is a possibility of functional restoration despite the fact that the individual end fibrills are directed backward in the connective tissue of the mucous membrane of the tongue and reach the musculature.

When the experiment is performed in a different order, i.e., with connection of the central stump of the lingual nerve to the peripheral segment of the hypoglossal, the progressing end fibers for the most part are directed to the collections of sarcoplasma of the old muscular end plates and here form hypolemmal nerve endings very similar to those which are present in the muscle tissue with ordinary regeneration. Only a small part of the terminal branches forms epilemmal nerve endings in the connective tissue.

A great influence on the shape of the terminal organs formed during the regeneration processes is exerted by the medium in which they develop. B. I. Lavrent'yev and M. A. Baron demonstrated the effect of local conditions on the formation of synaptic connections, studying the regeneration of preganglion fibers in the upper cervical sympathetic nodule.

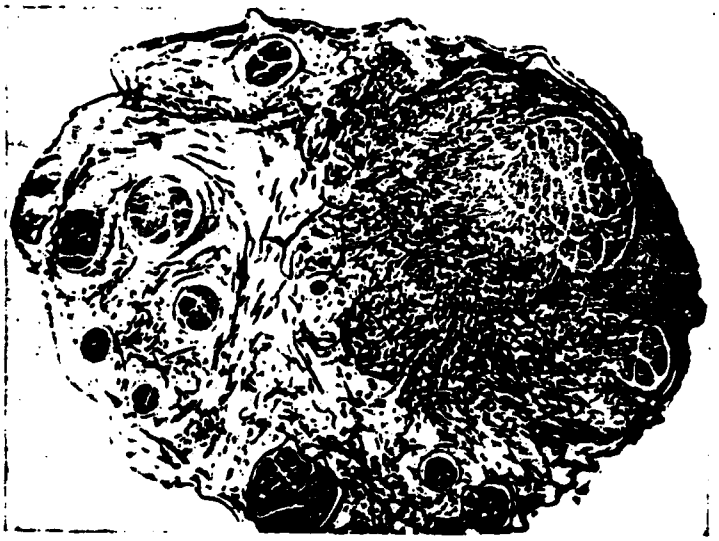
In the studies conducted under the direction of P. K. Anokhin, /80 physiological methods were used to determine regeneration after suturing different nerve trunks (the vagus and radial, the femoral and obturator). The restored function always corresponded to those formations on the periphery into which the newly formed nerve fibers had grown. The terminal organs never lost their specific characteristics and influenced the nerve centers, causing their adaptation to the new conditions.

## Traumatic neuroma

If on the path between two nerve segments there are any obstacles, as for example rough connective tissue, bone fragments, etc., then in the proximal segment there are formed a huge number of nerve fibers growing in the form of clumps. This picture is observed in amputation neuroma as well as in the partial severance of the nerve trunk. The neuroma may be formed even with retained continuity of the nerve trunk due to the presence of perineural and endoneural scar formations. It should be noted that scar changes, particularly in firearms wounds, may be present over a considerable extent. Infected wounds which suppurate for long periods provide particularly frequent reason for the emergence of neuromas in rough, calloused scar formations. Traumatic neuromas may lead, as we know, to severe irritation processes in the motor, sensory, and trophic areas. Pains and trophic disruptions undoubtedly occur more frequently with intrafascicular neuromas than with complete anatomical severance.

Traumatic neuromas may in time reach a considerable size. This is made particularly evident in studying the architectonics of neuromas on series cross-sections where it is possible to watch the gradual changes in the structure inside the nerve trunk and the formation of young fibers in the individual nerve fascicles (fig. 33) (B. S. Doynikov, B. A. Favorskiy). As concerns the histological specifics, first of all it is necessary to note that in old neuromas along with the pulpous nerve fibers, which are usually considerably thinner than the fibers of the corresponding nerve trunk, there is still a large number of non-pulpous fibers. The tangled path of the newly formed axial cylinders corresponds in general also to the location of the schwann cell chains. Often entire bands of newly formed reverse growing nerve fibers are observed, which surround the central stump or form circular and spiral rings in the perineurium of the individual nerve fascicles (fig. 34). Bands of fibers are encountered which penetrate through the scar membrane of the neuroma and stretch into its surrounding areas. Individual cellular chains contain non-pulpous axial cylinders, while others remain empty. It is also

necessary to indicate the frequent degenerative phenomena in old neuromas, along with which are noted reactive regeneration processes. The tendency toward regressive changes must be attributed to unfavorable nutrient conditions in the rough scar tissue for the stacked nerve fibers. Alongside the newly formed fibrills which are supplied by terminal bulbs, in old neuromas there are also end formations from long ago (B. S. Doynikov). Alongside the elementary "indifferent" pin-like endings surrounded by schwann cell protoplasm (fig. 35), there are complexly constructed, partially encapsulated end formations. "Free" branchings which end in the perineural, i.e.,/81 in the scar tissue, have varying form: these are either small branches supplied with end heads and similar to the end formation in normal connective tissue (fig. 36), or nerve endings which are frequently branching with fibrillar splitting of their end formations (fig. 37). The latter end formations are found more often in young neuromas. Often there is a clearly expressed close connection of the end formations with the connective tissue cells: the end heads are closely adjoining the cell nucleus and even form indentations in it (fig. 36).



/80a

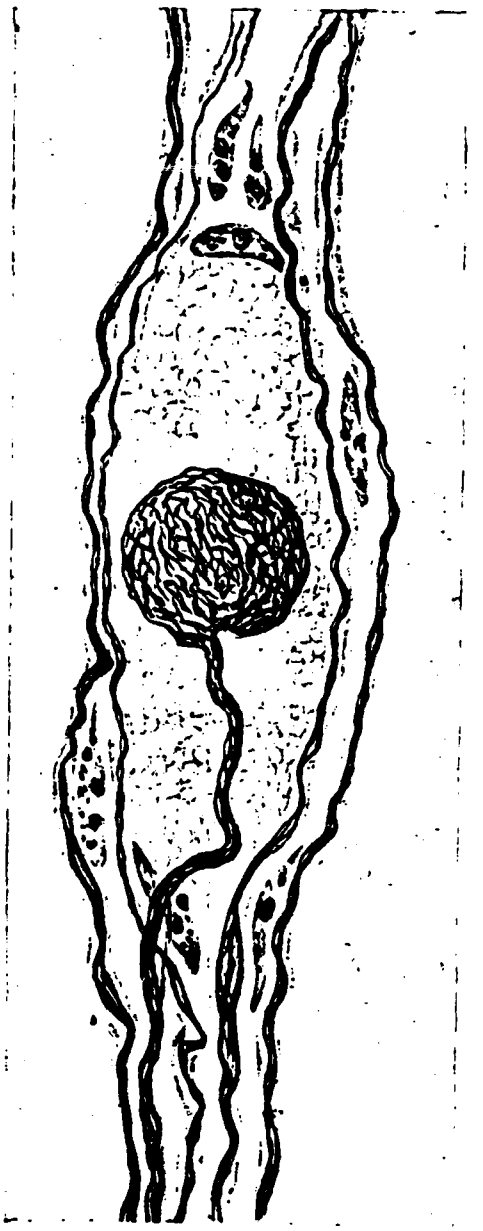
Fig. 33. Cross section of a two-year old sciatic nerve neuroma. Stain according to Veygert.

Fig. 34. Longitudinal section through a six-year old sciatic nerve neuroma. Impregnation with silver according to Kakhal.

Inside the capsules of nerve endings formed by the connective /81 tissue membrane adjoining with its inside to the schwann cells is enclosed either the axial cylinder with pin-line thickening (fig. 38), or an axial cylinder with multiple branchings and covered with a thin fiber. We cannot deny that in the latter pictures there is a certain similarity with the receptor end organs which are encapsulated and found in normal connective tissue. There is no doubt that such end organs in the tissue of a neuroma may cause certain clinical manifestations.

Filling large nerve defects and transplantation

Plasty, which is proposed for filling large defects in nerves, is based on various theoretical suppositions and changed accordingly with the study of regeneration. The methods of tubulization which were based on old concepts (Ranvier) of the growth of newly formed axial cylinders in the direction of least resistance must be discarded, since



/80b

Fig. 35. Simple ending of a nerve fiber in a neuroma. Impregnation with silver according to Kakhal.

the introduction of tubes from dead tissue or tubular foreign bodies into the area between the nerve endings only intensifies the inflammatory reaction and at the same time these methods do not create any conditions for the formation of a favorable scar structure.

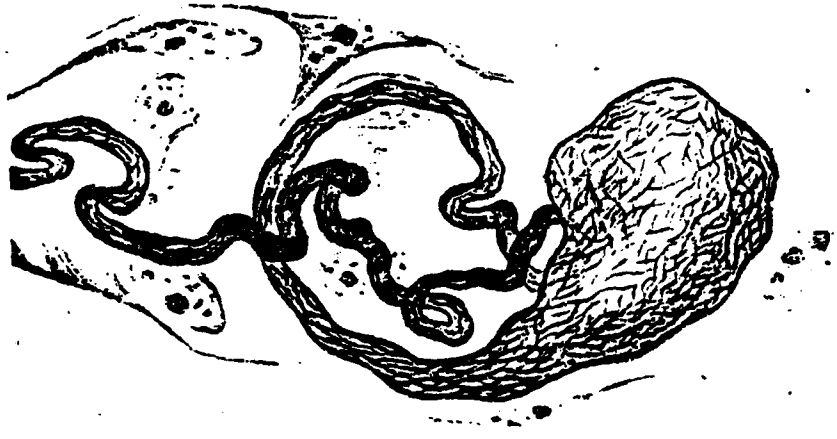
Subsequently, auto-, homo- and heterotransplants were used experimentally for the replacement of defects in the nerve, with various evaluations of the role of these nerve segments in the regeneration process. According to Bete, the transplanted nerve segment possesses active properties which do not dissapear when it is preserved on ice. The in-depth histological study of experimental homoplastic transplants performed by Bil'shovskiy showed that even a freshly introduced nerve is often subjected in its central parts to necrosis, and only isolated islets remain in which Waller degeneration is evident. The proliferation property of the schwann cells evidently soon diminishes with insufficient blood supply. The necrotic masses are partially removed by autolysis, while the introduced segment is replaced by connective tissue which grows primarily from the connective tissue elements of the central and peripheral stump. The emerging scar is distinguished by its favorable structure, since the growth of it connective tissue bands takes place primarily lengthwise and therefore the structure of the nerve membranes is retained. Such a scar is very favorable for the passage of schwann cell chains and young axial cylinders growing from the central stump. Nazhott, who proposed a method of implanting an alcohol-fixated segment of nerve trunk, assumed that the mechanical role of fixated tissue was the same as that of viable tissue. The number of operations performed by this method was very small. Success was noted in only 4.0% of those operated. The implantation of cat or rabbit spinal cord segments fixated in formalin or alcohol, proposed by Gosse and Bertran, which /82 according to the first reports of the authors soon gave in several cases a certain restoration of movement, did not attain widespread application. It turned out that the newly formed nerve fibers are directed not through the white substance of the spinal cord, but grow around the transplant along its periphery (N. V. Kovalenko).

/81a

Fig. 36. Free ending in a neuroma.
Impregnation according to Kakhal.

/81b

Fig. 37. Endings in a neuroma with splitting of the fibrillar strustures. Impregnation with silver according to Kakhal.



/81c

Fig. 38. Encapsulated nerve ending in a neuroma. Impregnation with silver according to Kakhal.

Fig. 39. Cross-section through a transplant (formalin-treated sciatic nerve of a horse), three years old in the sciatic nerve of a human. There is good retention of the fascicle structures and pulpous nerve fibers in the internal layers and partial dissolution of the fascicles in the external sections by introduced macrophages. Stain according to Veygert.

In 1939, A. P. Anokhina proposed the implantation of a nerve /82 trunk segment fixated in formalin, and favorable experimental results were obtained. In the course of the first years of the Great Patriotic War there were reports which indicated the emergence of indications of regeneration of damaged nerves, particularly a certain restoration in skin sensitivity with the use of this method for nerve trunk plasty. However, despite the series of positive properties of such implants (their good fusion with the ends of the severed nerve trunk, the lack of extensive growth of scar tissue in places of fusion and along the periphery of the implanted fixated nerve segment in most of the cases studied), the newly formed nerve fibers do not penetrate into their thickness, but grow merely along the periphery. Connective tissue elements with the vascular network are also exceedingly slow in growing into the thickness of the implant, as a result of which the formalin fixated nerve fiber fascicles are for a long time not subjected to the action of macrophages (V. V. Semenova-Tyanshanskaya (fig. 39), and the implant is a foreign body which is difficult to resolve on the path of the regenerating nerve fibers and which sustains a chronic inflammatory process in the nerve membranes.

Two circumstances make it necessary to be very careful in transferring the experimental data into clinical practice: the considerable length of the transplant, which is usually necessary in field combat wounds, and the considerable diameter of the large nerve trunks in the human extremities (with their exceedingly complex internal structure) with the multiplicity of nerve fascicles enclosed in very dense perineural membranes. Evidently, of all the proposed methods of nerve trunk plasty in man, preference must be given to autoplasty of fresh nerve trunks.

Thus, from the brief summary presented we must conclude that the rather difficult problem of closing extensive defects in injuries to the nerve trunks cannot be considered solved, and further study is required.

Regeneration and restoration of functions to an injured nerve

Clinical experience has shown that functional restoration after severance of a nerve is often incomplete, particularly in the distal regions of the extremities. A comparison of the results of physiological tests and histological studies leads us to conclude that the explanation for this must be sought in the functions and structure of the peripheral sections as well as in the corresponding nerve centers.

Of huge significance for the restoration of functions is the important property of damaged nerve fibers to give excessive branches of axial cylinders.

Individual schwann cell chains of the peripheral segment are neurotized by entire fascicles of young nerve fibers of various size, as a result of which the possibility is increased for the regenerating fibers to reach their adequate goal. Thanks to the increased nerve /83 connections in the path along the marginal periphery there may be a considerable increase in the area of innervation for each nerve trunk fiber, and along with this also for the corresponding nerve cells.

For substantiation of the complex and coordinated processes of regeneration, the significance of the periphery was stressed, forming the corresponding nerve endings and organizing the adaptation and restructuring of the nerve centers.

Speaking in favor of the selective functional specifics of the terminal organs is, for example, the fact of reverse growth of certain motor fibers which get into the epithelium during heterogeneous regeneration and which finally find their way to muscular tissue and form motor end plates.

The clinical treatment of nerve trunk injuries indicates a certain sequence in the restoration of protopathic and epicritical sensitivity and the frequent absence of restoration of epicritical sensory qualities, which was explained by various means. Ferster's assumption that algesic

fibers are restored more rapidly during regeneration has not yet been anatomically confirmed.

A comparison of the clinical manifestations and the histological picture in the case of traumatic injury to the ulnar nerve yielded the following results: while in the course of several months after the injury to the nerve in the area of innervation there was only protopathic sensitivity, with histological study of excised pieces of skin it was possible to establish the presence of a mass of nerve fibers with numerous nerve endings and terminal apparata in a condition of excessive growth. There were even sympathetic fibers along the vessels and around the sweat glands. Protopathic sensitivity, according to the data of the authors, arises as the activity of immature restored end organs. Non-localized, diffuse sensations may depend on insufficient myelinization of the newly formed fibers. Speaking in favor of such an interpretation is the analogy with motor regeneration -- normal movements are restored only when the strange and complex shaped nerve end plates gradually return to normal.

Aside from this, in judging the restoration of sensitivity in two stages, i.e., the appearance first of protopathic and significantly later of epicritical sensitivity, it is necessary to consider heterogenic regeneration of the sensory nerve fibers of various quality on the one hand, and on the other -- also the topographically non-correspondint homogeneous neurotization.

While the restoration of protopathic sensitivity must be preceded in general by the restoration of the connection between the corresponding terminal organs and the thalamus, it must be assumed that the restoration of finer sensitivity, particularly of localized sensations and proprioceptive sensitivity, will at first be without result with any heterogenic or topographically incorrect connection.

The gradually restored epicritical sensitivity leads to a restructuring of the centers, with the volume of possible restructuring being subject to great individual fluctuation.

## CHAPTER V

## ON THE ORGANIZATION OF TREATMENT-EVACUATION AID WITH FIREARMS INFLICTED WOUNDS TO THE PERIPHERAL NERVES

Among the problems of military field surgery, the questions of /84 the timely organization of neurosurgical aid with firearms wounds to the peripheral nerves are most complex. Their proper solution in the system of by-stage treatment with ordered evacuation was associated with a number of difficulties.

With wounds to the extremities, the trauma to peripheral nerves is often not accompanied by independent symptoms and becomes lost in the complex clinical picture of simultaneous injury to the various anatomical formations of the extremities. Medical aid in the early periods after firearms injury to the extremities usually consisted in the implementation of immediate first aid to the wounded and in combatting the severe, dangerous complications (shock, acute blood loss), which often accompany these injuries.

As illustrated by the experience of the Great Patriotic War, the volume and character of treatment-evacuation aid for firearms injuries to the peripheral nerves under military field conditions was determined not only by medical, but also be general tactical conditions.

Conditions of attack with intensive advancement of troops caused frequent relocation of field medical institutions in the presence of a large flow of wounded. This created extremely difficult situations for the timely diagnosis of injuries to the peripheral nerves in the combat and military region even for somewhat experienced neuropathologists and neurosurgeons. In these regions it was possible only in singular

cases to diagnose the injury of large nerve trunks (0.2%) accompanied by obvious symptoms of paralysis or agonizing pains resulting from a nerve pinched between bone fragments. The main body of wounded with trauma to the peripheral nerves, as a rule, was discovered only at the GBF [Gospital'naya baza front; Front hospital base] or in hospitals located in the internal region. Exceptions to this rule were presented by the slightly wounded who were treated at AGLR [Armeyskiy gospital' dlya legkoranenykh; Army hospital for light wounds] and in whom, although belatedly, it was possible to find injuries to the peripheral nerves and to organize corresponding treatment. The volume of aid during trauma to the peripheral nerves in the severely wounded amounted to preliminary treatment and immobilization of the extremity in a useful functional position.

On the home front, the conditions of medical stages of evacuation were calmer, since the flow of wounded was considerably reduced and field medical institutions were rarely relocated. Better conditions /85 were created in the military and army region for the diagnosis, sorting and ordered evacuation of wounded suffering from injuries to the peripheral nerves.

The most unfavorable conditions for diagnosis and for rendering aid to wounded with injuries to the peripheral nervous system were created during retreat or forces or during special operations conducted behind enemy lines. Full-fledged aid for wounds to nerve trunks under these conditions could only be organized with rapid and planned evacuation of the wounded from the combat zone.

The difficulties of early discovery of injuries to the peripheral nerves depended greatly on the character of injury to the extremity. The experience of the Great Patriotic War showed that injuries to the peripheral nerves were often combined with considerable damage to tissues, and often anatomical formations neighboring the nerve became involved, particularly the vessels, bones, and joints.

According to the materials for development of illness histories, wounds to the peripheral nerves were accompanied by simultaneous injury

to the bones in 45.2%, to major blood vessels -- in 5.4%. It must be stressed that with injury to the certical plexus, injury to the vessels was noted in 20.0%. Relatively frequently there were accompanying wounds to the vessels with combined injury of two or three nerve trunks. Thus, with combined injuries to the median and ulnar nerve, wounds to the major arterial vessels were noted in 9.2%, of the median and ulnar-- in 7.9%, and of the radial and ulnar -- in 4.0%. Injuries to the blood vessels were observed most rarely with injuries to the radial (3.1%) and the sciatic nerve (2.1%). In this complex symptomatic picture of wounds to the extremities, injuries to the peripheral nerves were manifested not as isolated occurrances, but represented accompanying manifestations, in connection with which they often lost their independent clinical significance and were not diagnosed in time. In the early period of such extensive trauma to the extremity with damage to the muscles, tendons, bones, and blood vessels, it is rather difficult to isolate nerve injury. In the first hours and even days after the injury, it was difficult to determine in what measure the motor and sensory deprivations depended on injuries to the bone or nerve. As we know, motor disorders after such injury may arise due to a bone fracture or breaks in tendons or muscles. Injury to the soft tissues leads to tissue concussion, and breaks of the small blood vessels. Serous impregnation of the small nerve trunks and their surrounding tissues, which conditions compression of the nerve fibers, causes sensory and motor disruptions in the corresponding extremity which soon pass.

Firearms injuries to the extremities with considerable tissue destruction were often accompanied by functional antagonistic or synergistic disruptions of nerves which were not directly damaged by the injury. In these cases, with the presence of polymorphous clinical symptomatics, it was difficult to recognize the damaged nerve trunks.

All this gave rise to the clinical complex of symptoms of functional disorders during the acute period of injury to the extremity in which it is difficult and sometimes even impossible to establish a diagnosis of injury to the peripheral nerve.

The character of treatment-evacuation measures and the timely diagnosis of injuries to the nerve trunks was to a considerable degree determined also by the level of the injury.

Among the specifics of wounds to the more distally located /86 regions of the extremities, we must note the generally recognized frequency of injury to the dorsal branch of the radial nerve, which accompanied a considerable number of wounds sustained in the area of the radiocarpal articulation. As a rule, damage to this nerve was recognized at more distant stages of evacuation, where the neuro-ischemic contracture began to be more clearly manifested.

Damage to the median nerve with injuries to the central third of the forearm was by far not always recognized at the preliminary stages of evacuation in connection with the fact that the main mass of motor branches of these trunks innervate muscles in the upper third of the forearm above the area of injury, as a result of which there were no motor disruptions.

Injuries to the radial nerve in the central third of the shoulder occurred in a very large percentage of cases as a result of direct wounding by a shell as well as by a bone fragment during fractures. The injury was easy to diagnose, although even here the greatest attention was given to the acute trauma.

The same is true also for injuries to the branches leading from the dorsal fascicle of the radial and axillary nerve with wounds sustained in the area of the shoulder joint. It should be noted that wounds to the upper third of the shoulder and the shoulder joint with destruction of the upper meta-epiphysis of the brachium or head, due to the massiveness of the osteal trauma and damage to the vessels, detracted the attention of treating doctors at preliminary stages away from the injuries to the nerve trunks in this region.

Wounds in the area of the lateral triangle of the neck with damage to the brachial plexus were among the most severe. In cases where they were accompanied by injuries to the large blood vessels, they often led to fatalities on the battlefield.

Injuries to the nerves in the leg and the blood vessels were often observed with wounds sustained in the area of the popliteal fossa. With these combined injuries, treatment measures at preliminary stages were reduced to rendering first aid for hemorrhaging.

With wounds to the upper third of the hip and the hip joint in the area of their anterior surface, combinations of trauma to the femoral nerve with injuries to the vascular fascicle were often noted. In the latter cases, the attention of the doctors was focused more on the dangerous manifestations associated with injury to the vessels.

Injury to the nerve trunk in the buttocks region must be related to one of the most severe injuries of the support-motor apparatus not only because of the disruption of the integrity of the nerve itself, but also because of the frequency of accompanying severe injuries to the hip joint, and wounds to the large muscular masses of the buttocks region often accompanied by damage to the organs of the small pelvis. The severity of these injuries not only hindered the diagnosis of injury to the nerve trunks, but necessitated the doctors at preliminary stages of evacuation to focus their attention primarily on rendering first aid. Subsequently, all these accompanying complications during the process of treating the wounded inevitably led to a prolonged period between the trauma and subsequent operative intervention on the nerve.

From that which has been said it follows that at the preliminary stages of evacuation, the diagnosis of nerve injury was often not pronounced, and often could not be pronounced. With injuries to the large blood vessels, bones, and joints, the discovery of injuries to the nerve trunks became secondary. The surgical tactics in these cases was reduced to measured directed towards combatting hemorrhaging and to rendering first aid for severe injuries to the support-motor /87 apparatus. Immobilization was performed in the following cases: when it was necessary to provide rest for the extremity in the case of bone trauma and after an operation performed on the vessels.

As a result of the facts indicated, firearms wounds to the peripheral nerves were recognized considerably later, starting with the military and primarily with subsequent stages of evacuation.

The organization of treatment measures with wounds to the peripheral nerves in the combat zone was limited to prophylactic measures in combatting wound infection and to rendering immediate first aid. It consisted of the following elements: a) rendering first and prephysician aid; b) timely introduction of serum and vaccine; c) providing immobilization of the injured extremity and preliminary surgical treatment of the wound.

Wounds to the peripheral nerves were often accompanied by extensive torn, crushed injuries to the soft tissues. Here the basic task in such wound cases in the combat zone was combatting primary and secondary infection of the injured extremity. From the materials for the development of illness histories it is evident that primary surgical treatment of wounds with injuries to the peripheral nerves was characterized by dissection and excision of soft tissues, removal of bone and metal fragments, and bandaging of the blood vessels (table 10).

Table 10

A description of preliminary treatment of wounds to the extremities with firearms injuries to the peripheral nerves (in percentages as related to the entire group of nerve trunk injuries)

| Character of intervention | Percentage of cases |
|---|---|
| Dissection of soft tissues..... | 44.70 |
| " and excision of soft tissues..... | 10.91 |
| " of soft tissues with removal of bone fragments | 5.22 |
| " " " " " bandaging of blood vessels | 3.13 |
| Dissection of soft tissues with removal of metal fragments | 0.40 |
| Application of a preliminary suture to the damaged nerve.. | 0.04 |
| Preliminary treatment of the wound according to the character of injury to the extremity was not indicated | 35.60 |

This methodology of surfical wound treatment sharply improved the course of pathological processes in the damaged nerve. Here it is also necessary to stress the significance of the times of removal of infection centers, foreign bodies, and necrotized tissue. Thus, according to the materials of development of illness histories, it has been established that preliminary wound treatment with injury to the peripheral nerves was performed in subsequent periods (table 11).

An analysis of table 11 shows that in the first 6 hours after injury, surgical treatment of the wound was performed in 19.7% (as related to the overall number of cases with injury to the peripheral nerves), within the first 24-hrs -- in 56.9%, and at a later period -- in only 9.5%.

The indicated early times for preliminary treatment with injuries to the peripheral nerves are an indicator of the brilliant organization of medical aid in the combat region and characterize its maximal /88 proximity to the combat lines.

Table 11

Times of preliminary surgical treatment of firearms wounds to the extremities with injury to the peripheral nerves (in percentages as related to the overall number of nerve trunk wounds)

| Time of wound treatment after trauma | Percentage of cases |
|---|---|
| Up to 3 hours | 5.5 |
| 3-6 hours | 14.2 |
| 6-9 " | 18.6 |
| 9-12 " | 5.8 |
| 12-16 " | 3.5 |
| 16-18 " | 2.3 |
| 18-24 " | 7.0 |
| Within 2 days | 4.5 |
| After 2 days | 3.0 |
| Treatment was not indicated | 35.6 |

The timely preliminary surgical treatment had a significant effect on the healing of the wound, the formation of the scar, and on the course of pathological processes in the damaged trunk of the peripheral nerve, as well as facilitating earlier performance of specialized surgical treatment.

Surgical wound treatment, depending on the operative-tactical situation at the front, was performed at various stages of evacuation. In the overwhelming majority of cases it was cone in the combat zone, considerably less frequently -- in the military station and in a very few cases -- at the front hospitals (table 12).

Table 12

Distribution by stages of evacuation of the number of cases of preliminary surgical treatment of firearms wounds to the extremities with injury to the peripheral nerves (in percentages as related to the overall number of nerve trunk injuries)

| Stage of evacuation | Percentage of cases |
|---|---|
| Combat troop area..... | 52.9 |
| Military area..... | 10.3 |
| Front line area..... | 0.6 |
| Other stages..... | 0.6 |
| Preliminary treatment by character of injury is not indicated..... | 35.6 |

As we see from the presented data, immediate surgical aid with firearms wounds to the extremities with injury to the nerve trunks was provided at relatively early times which, undoubtedly, facilitated the effectiveness of the specialized aid.

With injuries to the peripheral nerves combined with the simul- /89
taneous injury to bones in the extremity, all the attention of the doctors in the combat troop area was focused on rendering immediate aid associated with the bone fracture. This aid was reduced to the treatment of the wound with subsequent transport immobilization of

the traumatized extremity. The most important thing was to give the extremity its proper position which would guarantee against the spread of infection and wound complications. The position given to the extremity had to prevent the development of contractures, create the most favorable conditions for the course of regenerative processes in the injured nerve, and facilitate the restoration of muscular tonus. Used for this purpose were rather simple and at the same time effective means of immobilization -- mesh metal splints, wood or cardboard splints, Kramer and Dietrich splints.

With isolated injuries to the peripheral nerves or injuries accompanied by damage to the bonex, the fixation of the extremity in various positions was considered, depending on the character of injury to the bones, on the type of nerve and the level of its trauma (table 13).

Table 13

Immobilization of the upper extremities with damage to the peripheral nerves at stages of evacuation in the combat troop area

| Localization of bone injury | Localization of nerve injury | Character of immobilization | Position of extremity |
|---|---|---|---|
| Clavicle, scapula | Brachial plexus | Bandaging the upper extremity to the body and scarf bandage | Shoulder is in the adducted position, raised forward and upward, elbow joint is bent |
| Brachium | Radial nerve | Mesh, plywood, cardboard splints, Kramer splints. Bandaging the upper extremity to the body, scarf bandage | Shoulder in adducted position, lifted upward and forward, elbow joint is bent, hand and fingers in position of dorsal flexion with abduction of the thumb. |
| Same | Median nerve | Same | Shoulder in adducted position with maxiaml flexion in the elbow joint, forearm is supinated, hand and fingers in position of palmar flexio |
| " | Ulnar nerve | " | Shoulder in adducted position, lifted upward and forward, elbow joint extended, IV and V fingers extended. |

The immobilization of the lower extremity with injury to the sciatic nerve is performed with fixation in the flexed position in the knee joint and extension in the hip joint.

According to materials for the development of illness histories, temporary transport immobilization with wounds to the extremities accompanied by injuries to the peripheral nerves was used in 47.9% of all nerve trunk injuries.

Medical aid in the military region with injury to the nerve trunks in the years of the Great Patriotic War already began to take on a specialized character.

For provision of diagnosis and specialized medical aid, wounded /90 with peripheral nerve injuries, military KhPPG [Khirurgicheskiy polevoy podvizhnoy gospital'; Surgical mobile field hospital] were staffed with neurosurgical groups of ORMU .

In the military region, in connection with the necessity for evacuation sorting for further direction of the wounded, the need arose for precise diagnosis of wounds to the nerve trunks. Here the recognition of injuries to the peripheral nerve in the presence of severe wounds to the extremities also presented considerable difficulties. They were determined by certain anatomical-physiological and pathophysiological specifics in the course of the traumatic process of the nerve trunk and were conditioned by compensatory mechanisms: compensation, "anastomoses" between individual nerves (V. N. Shevkunenko); central components of trauma (P. K. Anokhin); parabiotic conditions of the nerve (M. N. Berezina and K. L. Rudashevskiy); reflex mechanisms and corresponding paralyses (S. N. Davidenkov), etc. However, under conditions of a specialized hospital in the military region, great possibilities were opened for the diagnosis of nerve trunk injury. Significant help in this respect was given by the most characteristic data on the loss of motor function during injury of the peripheral nerves, which is schematically presented below.

| Damaged nerve | Characteristic symptoms of loss in motor function |
|---|---|
| Radial | Loss of extension in the radiocarpal articulation and in the fingers |
| Ulnar | Loss of flexion of the IV and V fingers, contraction and extension of fingers, adduction of the thumb |
| Median | Loss of forearm pronation, hand flexion in the direction of the radial articulation, flexion of fingers from I to III, counter-position of thumb |
| Axillary | Loss of shoulder abduction |
| Musculocutaneous | Loss of flexion in the elbow joint when shoulder is in supinated position |
| Sciatic | Loss of flexion in the knee joint and movement of muscles below the knee joint |
| Femoral | Loss of extension in the knee joint |
| Tibial | Loss of plantar flexion and adduction of the foot |
| Fibular | Loss of dorsal flexion and abduction of the foot |

If with the aid of the clinical data presented above it was possible to establish the injury to the corresponding nerve, then the determination of the degree and character of this injury presented considerable difficulties. Of great significance in solving this problem were case history data and the sensations of the victim which accompanied the trauma. A significant role in this belonged to the methodology of clinical-surgical studies, which served as the basic premises in questions of early diagnosis and tactics of conservative or surgical treatment.

Due to the similarity in the clinical indicators of nerve trunk /91 injury in the early period of its trauma with functional as well as with anatomical disruption, primarily conservative physiotherapeutic treatment was used in the military region (AGLR). In the process of its implementation, it became possible to clarify the character of the injury, to achieve healing of the soft tissue wound, and to create more favorable conditions for clarifying the diagnosis as well as for determining subsequent tactics. Wounded with closed trauma to the

extremity (with contusions, fractures, dislocations) and with open -- with a small zone of damage to the soft tissues -- under favorable conditions were directed to the AGLR. In the latter, with the presence of neurological testing, great possibilities were presented for clarifying the injuries to the peripheral nerves and for performing the appropriate physiotherapeutic treatment.

The application of the noted therapy in the period of wound healing made it possible to determine the character of further treatment -- conservative or operative.

Wounded with open injuries of the soft tissues, with extensive zones of injury, as well as with wounds to the blood vessels, bones, or joints, required long-term treatment. They were directed to a GBF (front base hospital) or deep into the home front in accordance with their primary wounds.

In cases where at the preceding stage preliminary wound treatment was not performed for some reason and fragments were not removed, these operations were performed at the PPG [Polevoy podvizhnyy gospital'; Mobile field hospital].

With strict indications for a primary wound suture, the application of a nerve suture may also be indicated. According to the materials for the development of illness histories it was established that the operation of primary nerve suture application was performed in 0.04% of all cases accompanied by nerve trunk injuries.

The application of a nerve suture was counterindicated with nerve defects which required the extension of its ends for the purpose of bringing them closer together or with bone fractures. Also considered was the degree of injury to the surrounding tissues, contamination of the wound, time passed from the moment of sustaining the wound, etc.

The position established during the Great Patriotic War on the earliest possible times for operative intervention with firearms wounds to the peripheral nerves made it necessary to establish a preliminary diagnosis already at the first stages of evacuation and operation on nerve trunks in specialized hospitals, depending on the operative and medical circumstances, starting with the military and front regions.

The damaged nerve trunk is subjected to complex anatomical and pathophysiological changes, ending in the formation of a neuroma or in favorable functional restoration. Therefore, the damage to peripheral nerves was viewed as a single pathomorphological process having a certain anatomical content which changed subsequently depending on a number of circumstances and conditions. The most important of these were the following: 1) the level of injury, 2) the anatomical-topographical specifics of the injured nerve, 3) the pathomorphological specifics of the wound process, 4) accompanying infection, 5) the combined injuries to bones and vessels which complicate the course of the wound.

These circumstances, in combination with the conditions of a combat situation, served as the basic preconditions for the substantiation of the surgeon's tactics in nerve trunk injuries.

In the extended period between combat operations on certain /92 fronts in the military region, conditions presented themselves which allowed operative interventions of a restorative character in cases of injuries to the peripheral nerves. In connection with, at the Leningrad, Western, and certain other fronts in specialized KhPPG [surgical mobile field hospitals], sections were often created for rendering surgical aid for injuries to the peripheral nerves. The wounded were directed there for operations primarily from the AGLR [military hospital for light wounds]. In these hospitals, neurological testing and the performance of physiotherapeutic treatment made it possible to separate the contingents of wounded with injuries to the peripheral nerves subject to surgical intervention.

Indications for operation were comprised primarily of two factors: lack of success in physiotherapeutic treatment and presence of wound healing in the soft tissues of the extremity. The wounded with less severe injuries were subject to operative intervention who did not require lengthy post-operative treatment and were capable of continuing military service after completion of treatment.

According to the materials of medical reports from the Leningrad front it was established that in the second line KhPPG, hospitals for restorative surgery were created for operating on the peripheral nervous system. I. S. Babchin indicates that in the quiet periods, army neurosurgeons rather widely and successfully performed operative interventions with moderate severity nerve trunk injuries, which made it possible to complete treatment on location without evacuating the wounded outside the military.

In the periods of major battles, the operative activity of such army hospitals ceased in connection with the fact that they switched over primarily to receiving and rendering aid to wounded with cranial and spinal injuries. Usually, wounded with peripheral nerve injuries were not sent to specialized army hospitals during the period of active combat operations. They were evacuated to front hospitals and further into the home front in accordance with their primary injuries.

The treatment-evacuation provision at the GBF was also determined by the general tactical combat situation, but already took on a strictly specialized profile of treatment aid. At the GBF the need arose for creating specialized neurosurgical hospitals for the wounded, with sufficiently large sections for electro-physiotherapy, mud therapy, and exercise therapy which allowed the widespread implementation of principles of complex physiotherapeutic and surgical treatment. Specialized neurosurgical, neurological sections and hospitals made it possible to clarify more precisely and widely the nerve trunk injuries among the various injuries to the extremities; they provided conditions for planned conservative and operative aid, facilitated the

implementation of final sorting and evacuation into the deep home front for wounded with combined injuries to the extremities who were in need of longer treatment.

The treatment work of the GBF was constructed on the principle of complex therapy (conservative and operative). Thanks to the organization of well-equipped physiotherapeutic sections in the specialized hospitals, it became possible to widely utilize the various forms of physiotherapeutic treatment of wounded with injuries to the peripheral nerves before the operation as well as in the post-operative period. Exercise therapy was also widely used, and was conducted in the form of group and individual lessons.

The organization of hospital sections especially for rendering /93 surgical aid with injuries to the peripheral nerves provided for operative treatment of moderate severity wounds to the extremities. Thus, in the inter-combat period at the Western front hospital base there were often created surgical sections for 50-100 beds for wounded with peripheral nerve injuries. These hospitals were staffed by ORMU neurosurgical groups.

In the medical reports of the Leningrad front it was indicated that a large 500-bed hospital was organized especially for the treatment of wounded with nerve trunk injuries. Here, scientific development of a number of complex problems associated with this area of neurology and neurosurgery was also conducted.

Thus, treatment-evacuation provision at the GBF with injuries to the peripheral nerves took on the character of physiotherapautic and surgical aid rendered to the moderate severity group of wounded. Other more seriously wounded were evacuated to the home front.

In the overwhelming majority of cases of peripheral nerve injuries, a conclusive neurological diagnosis was pronounced and the necessary complex treatment was performed at a home front base hospital. It had huge specialized hospital resources for restorative surgery for peripheral nerve injuries. The organization of specialized

sections and hospitals deep in the home front not only facilitated the implementation of complex therapy, but also made it possible to conduct extensive scientific activity directed toward the solution of complex problems of morphology, clinical practice and therapy of firearms wounds to the peripheral nerves. During the time of the war, medical workers at various stages of evacuation, primarily those engaged on the home front, published numerous works on questions of firearms wounds to the peripheral nerves.

The great development of medical science in the Soviet Union, particularly the development of neurosurgery, made it possible to properly organize specialized medical aid. The neurosurgical science of the country of Socialism, with its creative achievements and successes, was placed at the service of the heroic Soviet Army during the period of wartime trials.

One of the decisive, most important preconditions for the success achieved by the medical service of the Soviet Army in the course of the Great Patriotic War was the fact that our Socialist homeland and Soviet plan management gave everything that was necessary for the specialized highly effective treatment of the wounded.

For the first time in history during the Great Patriotic War was such a high and clear organization of the military-medical service achieved in our military and on the home front. It was distinguished by its timeliness, by-stage sequence, and grandness in the scale of rendering medical aid. It made it possible to implement specialized surgical treatment for firearms wounds to the peripheral nerves.

The Great Patriotic War showed that the Soviet system of treatment-evacuation provision for the troops was the most progressive and scientifically substantiated.

## CHAPTER VI

## GENERAL SYMPTOMATOLOGY AND DIAGNOSIS OF FIREARMS WOUNDS TO THE PERIPHERAL NERVES

### General clinico-diagnostic indications of nerve trunk injury /94

The Great Patriotic War brought many new factors into the problem of injuries to the peripheral nerves, making it necessary to significantly change our old concepts.

The basic evaluation of the clinical picture of peripheral nerve injuries before the Great Patriotic War stemmed from a somewhat simplified description in accordance with certain schemes of neurological diagnostics. However, a thorough analysis of observations conducted during the first world war and partially reflected in the works of the 5-th session of the All-Union Neurosurgical Soviet indicated that certain other factors aside from the purely morphological are significant in the development of the clinical picture of peripheral nerve injuries.

The clinical uniqueness of the syndrome of wounds to the peripheral nerves, which does not depend on the size of the trauma or its character, is conditioned primarily by the topographo-anatomical specifics of each nerve. And here the role of innervational variants, the significance of various anatomical connections and interrelations with other nerves are exceedingly great.

A large role in the review of studies on the functions and injuries of peripheral nerves was played by the new data on the interrelation of nerves. The manifestations of these interrelations are quite varied. These data testify to the fact that the clinical picture of nerve injuries is determined not only by the structuro-morphological, but also by the functional-dynamic disruptions. The significance of the latter is much wider and more varied than was earlier believed.

The experience of the war showed that the structural-morphological and functional-dynamic factors in the injury of the peripheral nerves are in a certain interdependence. In particular, incomplete anatomical severance may be combined with wider, and sometimes with complete functional or some other type of dynamic disruption. Stemming from this, undoubtedly, is the more complex character of the clinical picture, which is not limited to the central symptoms along. Finally, in analyzing the clinical picture it is necessary to consider the role of the compensatory mechanisms (local, i.e., peripheral and central) which often have a great influence on the functions of organs or, more specifically, on their capacity to re-structure functions at the earliest stages of the trauma.

Clinical observations conducted during the Great Patriotic War /95 made it possible to stress the even greater significance of mechanisms of replacement, coordination and synergy in the process of restoring lost muscular functions. Thus, the lost function of one muscle is partially performed by another preserved muscle which, aside from its basic function, also partially carries the other. For example, with paralysis of the biceps muscle, the preserved brachio-radial muscle may perform part of the flexory functions. In certain cases, the replacement of functions takes place in a more complex manner as a result of the sum action of other muscles.

The topography of the wound channel has a great significance in the evaluation and interpretation of clinical symptomatics and in the development of surgical approach. In determining the direction of the wound channel, it is necessary to consider the position of the soldier at the moment the wound was sustained. This circumstance often clarifies the understanding of the clinical picture. Here it is necessary to study the entire extremity as a whole, to establish the pathological condition of the skin, muscles, tendons, vessels, bones, joints, ligaments etc., and to determine the importance of the nerve injury in the overall clinical picture.

In the later periods, firearms inflicted nerve wounds, combining with extensive defects, gave scars which constricted the tissues of the extremity as a result of the wound healing. Contractures were often formed whose origin was often evaluated as being neurogenic. Simultaneous injuries to the nerves and large vessels often caused ischemic contractures, which complicated the clinical picture. This circumstance must always be considered in expressing the diagnosis.

Firearms wounds to the nerves in proximal sections of the upper extremity were most often observed in combination with traumas to the vessels (brachial plexus, damage to the nerves in the superior brachial sulcus). Deep suppurative processes in the wound arising as a result of the development of dense inter-muscular scars, sealed up nerve trunks which had not been damaged up to this time. With fusion of firearms inflicted fractures, nerve trunks were often involved in the excess bone callouses, and already in the process of wound healing were not only symptoms of compression observed, but sometimes also a picture of complete severance of the nerve trunk.

Combined injuries of the nerves, muscles and tendons often conditioned such pathological positions of the extremities which at first glance might have been taken for poses characteristic for the injury of one nerve or another. The same is true for injuries to the bones and joined. The clinical picture was even more complicated in cases when, along with nerves, there was also damage to the bones, joints and soft tissues of the extremities, including the vessels. Here the neurological diagnosis must be presented only after a very careful and thorough examination.

The clinical picture with nerve injuries is comprised of motor, sensory, vasomotor, secretory and trophic disruptions. The degree of expression of functional disruptions developing as a result of nerve injuries depends on the severity and level of their injury, as well as on the anatomical functional properties of the nerve trunks. Thus, for example, due to the presence of a large number of sensory and

vegetative fibers in the median and tibial nerve, when these nerves are damaged, along with motor disruptions there are also expressed sensory, vasomotor and secretory disruptions, while with injury to the radial nerve there is primarily a disruption in the motor functions.

With complete anatomical severance, the motor function is more /96 sharply disrupted than with partial damage to the nerve trunk. The functional disruptions are also manifested more acutely with proximal nerve damage than with injuries in its distal sections.

Motor disruptions with peripheral nerve injuries are reduced to paralysis or paresis of the innervated muscles, with atrophy and reduction in their tonus and disruption of the tendonous and periostalic reflexes. The commonly known motor disruptions are presented in detail further in the description of injuries to the individual nerve trunks. It is necessary to stop on certain specifics of motor disruptions of a general character.

In evaluating motor disorders, it is important to keep in mind the possibility of the presence in one case or another of double innervation by means of anastomoses with retained nerves and anomalous muscular branches from another nerve. Thus, for example, the basic nerve innervating the forearm flexors is the musculocutaneous nerve, and additional innervation of the same muscles may be provided by the median and radial nerve. The superficial flexor of the II and III digit, and the long flexor of the thumb are innervated primarily by the median nerve, but the musculocutaneous and, less frequently, the ulnar nerves may also participate in the innervation of the above-mentioned muscles.

With insufficiently careful examination, if a series of mechanical moments is not considered (force of gravity, elasticity of fascia and tendons of the paralyzed muscles), a false impression may be formed of the presence of a paralyzed muscle. An example may be the presence of flexor movements of the fingers with extreme extension in the radiocarpal articulation with paralysis of the ulnar and median

nerve (fig. 40) and, on the contrary, extension of the fingers with sharp flexion of the hand with paralysis of the radial nerve.

In examining the active movements of the muscles, it is necessary to give the extremity a position which eliminates the mentioned replacement and pseudo-movements.

In the first days after injury to the nerve trunk, the disruption in the function of muscles innervated by it is usually combined with a loss of function in muscles which are not related to the innervation of the damaged nerve. However, often the indicated disruptions take place also in later periods after the wound is sustained (one or several months later). Some examples are: the disruption of flexion, adduction and abduction of the fingers with damage to the radial nerve; the absence of flexion in the foot and toes with injury to the tibial nerve; the loss of weakening of plantar flexion of the foot with injuries to the fibular nerve.

In individual cases the injury to only one branch is accompanied by loss of function of either all or most of the muscles innervated by the damaged nerve. An example may be wounded in whom damage to the cutaneous branch of the radial nerve on the back of the forearm was accompanied by loss of function in extending the hand and fingers or damage to the median nerve in the lower third of the forearm was combined with loss of the flexional function in the fingers and hand.

It is difficult to judge whether the indicated motor disruptions are an expression of the inhibition of segmental centers resulting from trauma ("reflex paralysis") or whether the loss of function in one group of muscles may entail the disruption in the function of other muscles participating in the combined work of the hand, fingers and foot, as proposed by S. N. Davidenkov. Although the mechanism of these disorders has not been fully clarified, nevertheless an underestimation of the possibility of their emergence may lead to an improper diagnosis and treatment. /97

As a result of injury to one or another nerve trunk, the antagonists may over-compensate, which leads to contractures. Thus, for example, paralysis of the radial nerve leads to a loss of the function of extension in the fingers, as a result of which the flexors innervated by the median and ulnar nerve over-compensate. Contractures may also arise as a result of the injury to joints, tendons, muscles, bones, and skin. The efforts of wounded to retain a position of the extremity which eliminates or reduces pain may lead to an "anthalgic contracture".

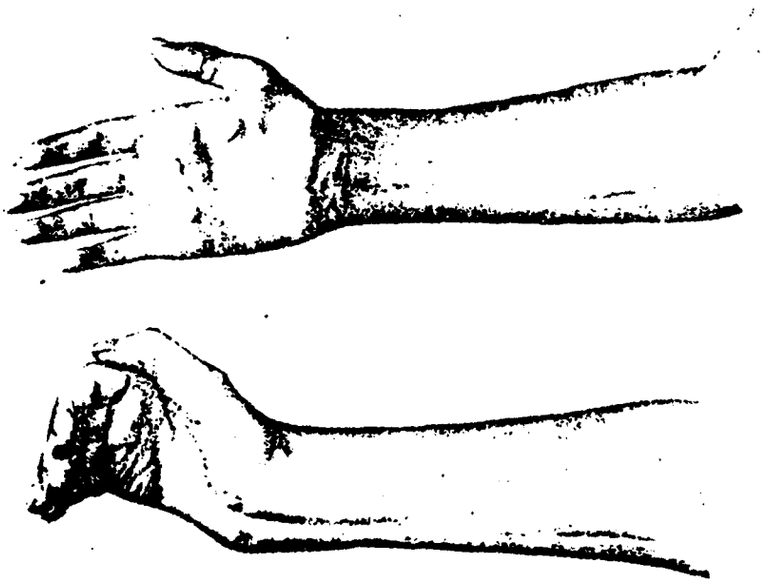


Fig. 40. Wound victim G. with injury to the ulnar and median nerve at the level of the upper third of the shoulder. With maximal extension there is a false impression of finger flexion.

It is necessary to isolate the group of patients in whom the area of the contracture does not correspond to the value and severity of the anatomical injury -- we are speaking of the so-called reflex contractures, which according to the materials for the development of

illness histories were noted in 0.5% of the cases. According to the materials of medical reports from the Leningrad front, injuries to the peripheral nerves were accompanied by reflex contractures in 2.3%.

In view of the fact that a special chapter is devoted to reflex contractures, we will limit ourselves to a brief indication of the most characteristic indications of this unique complication of wounds to the extremities. Reflex contractures develop most often as a result of wounds to the distal areas of the extremities, often combined with paralysis. The types of contractures are varied: thus, there /98 may be a flexion contracture in the elbow joint, a flexion and extension -- in the radiocarpal joint with odd changes in the position of the fingers; a "frozen" or "welded hand" is sometimes found. Observed on the lower extremities are flexion and extension contractures in the knee, less often in the hip, and most often in the ankle joint. These motor disruptions are usually accompanied by vasomotor and trophic disruptions. A characteristic feature of reflex contractures is usually considered to be the stability of the disorders. However, in individual cases there has been rather rapid cure after the application of psychotherapeutic measures.

As a result of injury to the nerve trunks, changes take place in the neuromuscular apparatus which are found by various tests: the electric excitability of the muscle nerve trunks, chronaximetry, and finally, recording action and rest currents (electromyogram).

Hyperkinesia with nerve injuries is rarely observed. In individual cases, when the nerve damage is accompanied by severe causalgic syndrome, there is sometimes observed a trembling of the fingers and the hand reminiscent of the tremor in Parkinson's disease. The rhythmic twitches of the II finger with reflex contracture in one wounded patient are described by Yu. V. Vasilenko. A. I. Geymanovich believes that with irritation of the median nerve there is a compression of the hand into a fist, and with irritation of the ulnar nerve the hand may take on an extrapyramidal placement. In individual cases of damage to the sciatic nerve, A. I. Geymanovich observed an extension spasm of the food. We have also observed analogous cases.

Disruptions of the tendinous and periosteal reflexes. Changes in reflexes with firearms inflicted injuries may be manifested differently, and it is necessary to consider not only the role of disrupted conductivity of the nerve trunk, but also the trauma to the entire motor apparatus.

With injury to the radial nerve, even with its high injury, reflex from the triceps muscle was preserved. (In individual cases with the presence of a flexion contracture in the elbow joint, a blow to the tendon of the triceps muscle is accompanied by flexion of the forearm). Often there was no carpo-radial reflex elicited with injury to the median nerve, or individual components of it were lost (flexion of the hand, fingers). Sometimes when the indicated reflex was caused, a clear extension of the hand was noted.

It should be noted that the absence of reflexes from the biceps and triceps muscle and carpo-radial reflex is a constant indicator of complete disruption of conductivity in the brachial plexus.

The achilles reflex was absent with full disruption of conductivity of the sciatic nerve. It was often lost also with partial injury to it, even with primary damage to the fibular portion, as well as in patients with isolated damage to the fibular nerve. Often the achilles reflex was not evoked in patients whose damage to the sciatic nerve was accompanied by very insignificant motor and sensitivity disruptions, and sometimes when the indicated disruptions were fully restored.

The plantar reflex was lost with complete disruption of conductivity in the sciatic or tibial nerve, but often it was absent with isolated injury to the fibular nerve. In wounded patients with partial damage to the sciatic nerve with the presence of hyperpathia on the sole of the foot, the study of the plantar reflex quite often caused /99 a general violent reaction.

Sensitivity disruptions resulting from injury to the peripheral nerves may be manifested in the form of loss (hypestesia or anes-

thesia) as well as in the form of irritation (hyperesthesia, paresthesia and pains) (table 14).

Table 14

The relation of frequency of sensitivity disruptions with injuries to the peripheral nerves

| Character of sensitivity disruptions | Percentage of cases |
|---|---|
| Hypesthesia | 60.4 |
| Anesthesia | 31.1 |
| No disruptions | 2.6 |
| Causalgia | 2.4 |
| Hyperesthesia | 2.1 |
| Combined sensitivity disruptions | 0.8 |
| Palpation soreness of nerve trunks | 0.5 |
| Hyperpathia | 0.1 |

By the degree of expression of sensitivity disorders with complete disruption of nerve trunk conductivity, we may isolate: the autonomous zone (the area innervated by only one nerve, in which anesthesia is observed); the mixed zone (the area supplied by nerve fibers from the primary and neighboring nerves, in which hypesthesia is observed).

This hypesthesia is often characterized by certain specifics, namely: deep sensitivity to pain is retained, which is particularly apparent by pinching, as well as the perception of sharp temperature effects (protopathic sensitivity); tactile sensitivity, the articulo-muscular sensation and particularly complex forms of sensitivity are not so well retained (sense of localization, the ability to distinguish two qualitatively and quantitatively similar stimulants -- epicritical sensitivity. Slight pin pricks on the appropriate part of the skin are not felt at all, but with stronger irritation the sensation of pain immediately takes on an inadequate intensity and is accompanied by a sharp affective coloration -- the pain remains for a certain period after the irritation is applied. The indicated unique sensitivity disruption is usually called hyperpathia. The manifestation of the latter has significant diagnostic value.

Conductors of gross pain and temperature, or protopathic, sensitivity, as we know, are the small caliber nerve fibers. They are the most resistant to the effects of various harmful elements and have the greatest capacity for regeneration. Therefore, in cases when sensitivity disruption of a hyperpathic character is discovered immediately after injury to the nerve trunk, this indicates the partial disruption of its conductivity. The manifestation of hyperpathia a certain period after the wound is sustained testifies to the fact that regeneration has begun. As epicritical sensitivity is restored, the manifestations of hyperpathia disappear.

The presence of hyperpathia significantly worsens the condition /100 of the patient. This is particularly apparent with regeneration of the sciatic nerve. With restoration of deep pain sensitivity, the wound victim cannot always place his weight on his leg due to the sharp pain accompanying this action and which arises despite the presence of analgesia in the superficial layers of the sole.

Numerous works in the Shevkunenko school have proven the frequency of anastomoses between the nerve trunks. This is particularly true of the nerve trunks in the upper extremities. In individual cases one or another part of our body is supplied only by a single nerve trunk, and in other cases -- by neighboring or two combined trunks. This explains to a considerable degree the frequency of non-correspondence between zones of sensitivity disruption and areas of distribution of cutaneous innervation of the given nerve. Nevertheless, existing schemes of peripheral sensitivity innervation have played a significant role in the diagnosis of wounds to the peripheral nerves, as demonstrated by the experience of the Great Patriotic War.

The most constant are the autonomous zones of cutaneous innervation, although they too are subject to individual variation. The least constant is the autonomous zone of the radial nerve. Sometimes with complete anatomical severance its sensitivity disruptions may be absent, or are apparent only through examination with a Weber circle. The autonomous zones of the other large nerve trunks are

distinguished by their great constancy. Thus, for example, for the ulnar nerve this zone is limited to the part of the hand in the area of eminence of the fifth finger, the skin of the entire fifth finger, and the palmar surface of the ulnar ridge of the IV finger. For the median nerve the autonomous zone encompasses the area of skin on the central and terminal phalanx of the indicator and middle finger. With anatomical severance of the sciatic nerve, anesthesia spreads to the outside surface of the shin and the entire foot, with the exception of its inside surface and the medial portion of its dorsal area.

Often with complete anatomical severance of a nerve verified on the operating table, in the zone of cutaneous innervation of the damaged nerve there is found a retention of sensitivity, often of a hyperpathic character. Sometimes this sensitivity is manifested immediately or several days after resection of the nerve trunk. In the latter case it is as if the operation facilitates the "functional manifestation" of the nerve fibers which have penetrated into the peripheral segment by indirect means from the central end of the same nerve or through anastomoses from neighboring nerve trunks. A. G. Molotkova and V. L. Lesnitskaya point this out in their articles.

Proprioceptive sensitivity (articular-muscular and vibration sensation) often suffers with injuries to the nerve trunks. The most often studied is the disruption of articular-muscular sensation, which with injury to a single nerve is disrupted only in the joints innervated by the one nerve. For example, with injury to the ulnar nerve, the articul-muscular sensation is lost in the fifth finger, less often -- in the IV finger,with damage to the median nerve -- in the interphalangeal articulations of the indicated finger. With isolated injury to the radial nerve, the articulo-muscular sensation remains intact. It does not change with isolated injury to the branches of the sciatic nerve and is lost in the toes if the fibular and tibial nerves are damaged simultaneously.

Very scant information is available on the disruption of vibratory sensation ( discerning the vibrations of a tuning fork when it is placed against individual areas of the extremities) with damage to the nerve trunks. Of the works which were published in the period of /101 the Great Patriotic War and devoted to the pathology of vibratory sensation with nerve injuries, we should indicate the studies of Kh. M. Freydin and I. Yu. Kokhanovskiy. Based on the study of 41 wounded patients, Kh. M. Freydin came to the conclusion that the curves for disruption of vibratory sensation with injuries to individual nerves are constant for a rather prolonged period of time. There are no data on the dependence of degree and level of injury to the nerve trunks. More concrete information was obtained by I. Yu. Kokhanovskiy in studying 40 wounded patients with nerve trunk injuries to the upper extremities. He established that for injury to the radial nerve there was a characteristic reduction in vibratory sensation on the entire back of the hand. Its complete loss could not be determined even with total anatomical severance of the nerve. With the background of reduction of vibratory sensation in the entire hand with isolated injuries to the ulnar and median nerve, with complete anatomical severance in the first case it was lost in the fifth finger and sharply reduced in the IV finger. With damage to the median nerve, a complete loss of this type of sensitivity was noted in the interphalangeal and a sharp reduction in the phalangeal articulations of the indicator and middle finger. With simultaneous injury to the ulnar and median nerve, vibratory sensation was lost in all the fingers, with the exception of the thumb.

The phenomenon of irritation of sensitivity in the form of paresthesia and pains with injury to the nerve trunks is observed often. Thus, for example, according to the materials of personal observations of 1,500 wounded patients with nerve damage, the manifestations of irritation were noted in half of the cases. Pains and paresthesia usually project into the area of the terminal branches of the damaged nerve. They may arise at the moment of injury, several days later, as well as in later periods after the wound is sustained.

The sensation of the extremities being torn off ("blown away", "torn off") at the moment the wound is sustained was most often noted in patients with anatomical severance of the nerve trunk. With partial damage to the nerve, the wounded patients most often ex-erienced a feeling of numbness, torpor, burning, a sensation of passage of electrical current. The patients experience all these sensations in the distal areas of the extremities. Often patients with damage to the sciatic nerve in the upper regions of the hip had a sensation of damage to the foot or the toes. The listed pain sensations which arise spontaneously may be manifested with pressure on the central stump of a damaged nerve, as well as along the course of the nerve trunk, with its partial damage or during the onset of regeneration.

The experience of the Great Patriotic War showed that cutaneous nerves play a significant role in the mechanism of the emergence of reflex contractures (N. A. Popov), reflex paralyses (F. M. Lampert), and causaglia (A. G. Molotkov). In analyzing the materials of personal observations encompassing 40 cases of simultaneous injury to the ulnar and median nerve accompanied by causalgic syndrome, in 34 cases there was discovered damage to the cutaneous nerves of the shoulder and the forearm. Of 25 cases with severe causalgic syndrome, 13 had injury to the cutaneous nerves.

Deserving of particular attention in nerve trunk injuries is a unique syndrome which includes burning pains, vegetative-trophic disruptions and psychical changes, and known as causalgia.

In conclusion to the section on sensitivity disruptions, it is necessary to pause briefly on illusory sensations experienced by patients with nerve trunk injuries. Baronov described illusory movements in 5 patients with partial nerve damage. More detailed data on sensations with nerve trunk damage are present in the work /102 of V. I. Frenkel'. He studied 170 wounded patients with nerve injuries to the extremities. Their sensations bore a varied character: incorrect perception of the position of the wounded extremity, a

sensation of non-existent motion (most often slow, rarely -- faster flexion and extension of the fingers), absence of support, deep distortion in the concept of the extremity -- its size, volume, sensation of complete absence of the extremity, particularly at the first moment when the wound was sustained. Such false sensations may last from several days to a year or more. The zone of distribution of false sensations is wider than the zone of innervation of the injured nerve. False sensations differ from phantom sensations after amputation by their greater localization and absence of pain. In all cases with false sensations, superficial sensitivity was disrupted. Articulomuscular sensation was retained in 58.0% of the cases. The dependence between the character and degree of expression of the described false sensations and the degree of disruption in nerve trunk conductivity could not be established.

Vascular, secretory and trophic disruptions were observed often with damage to the peripheral nerves, particularly to the median, tibial and sciatic nerves. In those cases when the injury to the nerve trunks was accompanied by vascular damage, the indicated form of disruptions is expressed in a more acute degree.

Vascular disruptions with damage to the nerve trunks are reduced to arterial hyperemia, cianosis, sometimes alternating with areas of hyperemia in the form of spots. With the aid of capillaroscopy, it was possible to obtain a series of interesting data on the changes occurring in the capillary network. A. Ye. Nil'sen observed these changes in 100.0% of all his cases (observations conducted on 93 wounded patients). With motor disruptions accompanied by insignificant pains, expansion of the venous part of the loop was noted (congestive hyperemia). In those cases where nerve damage was accompanied by sharp pains, spasm of the capillaries was most apparent. In patients suffering from causalgia this was combined with an expansion of the precapillaries. G. A. Rikhter observed a predominance of capillary contraction in 200 wounded patients. In studying patients suffering from causalgia, he discovered a unique reaction of the vessels to

cooling and heating: in the first case an expansion is noted, and in the second -- a constriction of the capillaries.

Vascular disruptions were usually combined with a reduction in the temperature of the damaged extremity (by 2-3°). This reduction was noted in areas which were outside the boundaries of zones with disrupted superficial sensitivity. With nerve trunk injuries accompanied by pains in the damaged extremity, particularly in areas of hyperpathia, there was an elevation in temperature.

The photoreactivity of the skin changes with damage to the peripheral nerves: quartz irradiation of the zone of cutaneous innervation of a damaged nerve with full disruption of its conductivity occurred without erythemic reaction; it was acute and retained for a long periods in injuries accompanied by pain.

Of the secretory disorders, the most constant and rather precise indicator of the disruption in conductivity of most of the basic nerve trunks are disorders in perspiration: anhydrosis -- on the a damaged extremity with complete disruption of nerve conductivity, reduction in perspiration -- with partial damage to the nerve trunk. If in the latter case there were manifestations of nerve irritation, hyperhydrosis was noted. The indicated disruptions in perspiration were usually observed in areas with disrupted superficial sensitivity. This generally known position on perspiration disorders with /103 nerve injuries was confirmed, and with certain additions, in the studies conducted during the Great Patriotic War by the method of V. L. Minor as well as by the electrometric method (N. I. Grashchenkov, A. S. Mirochnik, A. Ye. Kul'kov, I. Ya. Sergeyev). With severe forms of causalgia, anhydrosis was observed more frequently. The loss of the perspiration function set in immediately after removal of the sympathetic nodules. With complete disruption of nerve trunk conductivity, anhydrosis in the areas of cutaneous innervation of the given nerve was often accompanied by hyperhydrosis in the areas of neighboring nerve innervation. An exception was the radial nerve, whose injury usually took place without disruption of perspiration.

Sometimes the restoration of perspiration was the first indication of the beginning of restoration in the conductivity of the nerve trunk, and on the contrary, the increased inhibition of perspiration coincided with other indications of worsening in the nerve trunk conductivity. Thus, the dynamics of perspiration disorders may have a diagnostic as well as a prognostic significance.

As we know, a pinch or the application of faradic current in the area of the trapezoidal muscle leads to the appearance of a pilomotor reflex (usually the skin gradually gets goose bumps, beginning from the place of application of the stimulus and further along the entire half of the torso, and then along the entire body). With damage to a peripheral nerve, there is a noticeable free field in the area of cutaneous innervation of the damaged nerve with a background covered with goose bumps. This position was confirmed in the observations of M. Yu. Shereshevskaya, who attributed the same topical significance to this reflex as to the disruption in perspiration.

Trophic changes in skin and its derivates (hair, nails) are often observed with injuries to the nerve trunks. Thus, according to the materials for the development of illness histories it was established that trophic changes of the skin were noted in 7.8% as compared to all nerve trunk injuries. Of these, with firearms injuries, trophic disruptions were noted most frequently with injuries to the nerves in the lower extremities and more rarely -- with injuries to the upper extremities. This is also confirmed in the materials of medical reports from the Leningrad front, according to which wounds to the peripheral nerves were accompanied by trophic disorders in 6.7% of the cases.

Trophic changes were particularly acutely expressed in wounded patients with combined injuries to the nerves and vessels. The skin may have smooth folds and pale, or it may be shiny, tight, and have a purplish tinge. Sometimes the skin changes are reminiscent of ichthyosis, or psoriasis. Hyperkeratosis is often noted, limited sometimes to the area of cutaneous innervation of the damaged nerve (fig. 41, 43, and 44).

Changes in the nails -- brittleness, dryness, the appearance of transverse lines, ridges and depressions -- are among the number of constant indicators of nerve trunk injuries. The color of the nails becomes grayish brown, yellowish, and they lose their shine (fig. 42).

According to the materials for the development of illness histories, changes in the nails of a hyperkeratosis character were found in 0.1% of the cases as related to all nerve trunk injuries. Of these, they were most common with injury to the median nerve -- in 0.3%.

The listed trophic disorders usually develop slowly and reach a maximum in later periods after the wound is sustained. However, they may arise in the next few days after the trauma is sustained and may /104 develop rapidly. This applies to wounded patients in whom the nerve damage is accompanied by sharply expressed manifestations of irritation (for example, with severe causalgia). Trophic disorders, like vascular and secretory, develop most often and are most acutely expressed primarily with injury to the median or sciatic nerve.

Fig. 41. Hyperkeratosis of the back of the hand and fingers with partial injury to the median nerve in patient K.

Fig. 42. Deformity of the nails on the II and III fingers in patient B. with partial injury to the median nerve and the brachial artery.

Fig. 43. Hyperkeratosis of the sole of the foot in wounded patient T with partial injury to the sciatic nerve.

Hypertrichosis often spreads beyond the limits of the area of /104 cutaneous innervation of the damaged nerve. Since the intensified growth of hair is often observed in wounded patients without nerve damage, the diagnostic value of hypertrichosis with injuries to the peripheral nerves is insignificant.

With firearms wounds to the nerves, particularly in those cases when these injuries are accompanied by manifestations of irritation, in the bones of the extremities, primarily in their distal regions, x-rays reveal thinning of the bone in combination with decalcination (osteoporosis). The degree of expression of the osteoporosis depends

on the specifics of the intra-trunk structure of the damaged nerve. Thus, for example, osteal changes are more acutely expressed with damage to the median nerve and are minimal with injuries to the radial nerve.

Unlike osteoporosis, which is caused by inactivity, trophoneurotic osteoporosis develops early (on the average in the 2-3-rd week after the wound is sustained), spreading uniformly to all the bones of the hand and foot. Only rarely in a background of general osteoporosis is there a more acute expression of it in the innervation zone of the damaged nerve (S. N. Davidenkov, I. Ya. Sergeyev et al.). In later periods after the wound is sustained (a year or more later), x-rays reveal a thickening of the osteal trabeculae with enrichment by lime, but without their increase in size (Ye. M. Gol'tsman). In this period osteolyses are often noted (aseptic resorption of the bone tissue). Osteomyelitis may develop with the penetration of infection (suppuration, sequestration). According to the data of A. G. Molotkov and S. N. Davidenkov, changes in the bones with nerve injuries are sometimes reminiscent of changes with syringomyelia, Reno's disease, or tabes dorsalis.

Trophic ulcers arising as a result of nerve trunk injuries deserve particular attention. They develop most often on the sole or the foot with injuries to the sciatic nerve. According to the materials of personal observations, the ulcers are often localized on the margins of overlaps in cutaneous nerves. According to the materials for the development of illness histories, such ulcers are noted in 0.5% of the cases.

A. L. Polenov affirms that the trophic ulcers which are typical for the sole of the foot do not develop on the upper extremities. Here more often are observed phlyctena type formations in the form of blisters, sometimes with subsequent ulceration, located primarily on the palmar surface of the skin of the end phalanges or at the very tips of the nails. According to materials of personal observations, trophic ulcers occurred after a burn or chilling and with injuries to

the nerves on the upper extremities, but these were observed incomparable less frequently and were not acutely expressed. In studying wound injuries accompanied by ulcers on the sole of the foot it turned out that these trophic disorders arose most frequently in patients having simultaneous injury of the vessels and nerves. Ulcers arose in later periods (no less than a year after the wound was sustained) with complete anatomical severance of the nerve, and considerably sooner with partial damage to the nerve (fig. 45).

Vascular and trophic disorders may remain after restoration of movement and sensitivity, which considerably reduces the function of the extremity. Under the effect of chilling, burns, or contusion /105 there may develop ulcers which do not heal for a long time. Therefore, in studying wounded patients with nerve damage, it is recommended that particular attention be given to the condition of trophics.

Fig. 44. Growth of nails on the toes of wounded patient R. with partial injury to the sciatic nerve.

Fig. 45. Trophic ulcer on the left heel of wounded patient S., occurring as a result of injury to the left sciatic nerve and ligation of the femoral artery on the same side.

In conclusion it must be noted that during the time of the Great Patriotic War, morphological data on the histological changes in areas of the nervous system which were significantly removed from the area of injury of one nerve trunk or another were accumulated (B. A. Favorskiy). Changes "at a distance" were confirmed in the works of physiologists and clinicians (repercussive manifestations). We must agree with P. K. Anokhin, who considers that "nerve trauma has ceased to be merely a peripheral episode, but has come to be viewed as a particular expression of the inevitable trauma to the central nervous system".

Electrodiagnostics of firearms injuries to the peripheral nerves

In solving the problems of electrodiagnostics in cases of firearms injuries to the peripheral nerves, a number of specific difficulties have arisen, which in the time of the Great Patriotic War were successfully overcome by Soviet physiologists and physicians. The fact that numerous Soviet physiologists under wartime conditions were included in the medical work of the rear hospitals undoubtedly facilitated the practical introduction of physiological methods for nerve study. This was necessary because in the pre-war years a general situation of unsubstantiated well-being had been created in this area of physiological study. As a result of an entire series of works by major physiologists in our country and abroad, an insufficiently clear concept was formed, as it became apparent during the war, concerning the advantages of certain generally accepted methods of nerve study, particularly the chronaximetric method. It was believed that this method represented the most precise means of diagnosing the condition of the nerve and the muscles. Leading to this conclusion were primarily studies conducted on small experimental animals (frogs) and in the overwhelming number of cases on a nerve consisting of normal fibers. The experience of the war showed that doctors must always deal with such nerves which, as a result of injury, are heterogeneous in the physiological properties of the individual nerve fibers. It is specifically this circumstance which was not considered by those physiologists

and clinicians who widely propagandized the chronaximetric method for hospital studies. Lapik and Burgin'yon, who proposed this method, did not indicate the limits of its application in clinical practice. Therefore military doctors working in hospitals began using chronaximetry on an excessively wide scale.

From that which has been said it follows that Soviet physiologists, entering the hospital work under conditions of the Great Patriotic War, had to conduct studies of two types: 1) first of all it was necessary to thoroughly check all methods which were considered to be precise methods of electrodiagnostics under peacetime conditions; it was necessary to indicate their shortcomings and the limits of their application under conditions of pathology; 2) it was also necessary to develop new means of electrodiagnostics which would give the doctor more accurate information on the condition of the nerve trunk and muscles, and which would at the same time be easily accessible. The clinicians felt the need for such new methods already from the very first steps taken in their work with the chronaximeter in the hospital setting. Many neuropathologists expressed doubts when, with the /106 presence of sharply expressed clinical defects in the extremities and their nerves, the physiologist entered into the case history a diagnosis of: "chronaxy of the nerve is normal". Several hundred special studies were needed to discover the reason for this error which was at first incomprehensible and to show that the latter was conditioned by the very principles of the study of chronaxy. Here we must note yet another important circumstance, namely the extremely inadequate knowledge of the pathogenesis of wartime nerve trauma.

Our country's physiology has achieved exceptionally great success in the problems of pathology of the traumatized nerve. Numerous new studies conducted by Soviet physiologists in the hospital setting make it possible to say that the study of this problem is being conducted on a high scientific level. We must note particularly that our country's physiology, stemming from the ideas of I. P. Pavlov, did not limit itself only to the recognition of local peripheral changes in its evaluation of a trauma. In an entire series of works it was demonstra-

ted that immediately after the nerve trauma, it is possible to find in the overall complex of symptoms clear indications of the participation of nerve elements at various levels of the central nervous system in the pathological process -- inclusive up to the cortex. Along with this it was shown that the entire process of restoring the functions of a wounded extremity is under constant cortical control. It is only in recent years that studies are beginning to appear in foreign countries concerning the questions developed by physiologists of the Soviet Union over 10 years ago.

The evaluation of methods of electrodiagnostics used under hospital conditions should be begun with an examination of the methods of so-called classical electrodiagnostics. According to the materials for the development of illness histories, the methodology of electrodiagnostic study was used in 9.0% of cases of firearms wounds to the peripheral nerves.

Due to the fact that individual patients came to various hospitals at different stages of treatment, the need arose for a comparative evaluation of the various methods of electrodiagnostics.

Standard methods of clinical electrodiagnostics

Normal nerves and muscles of a healthy person react to galvanic as well as to faradic current. When the peripheral nerves are injured, a quantitative and qualitative disruption is noted in the electro-excitability of the nerves and the contractive capabilities of the muscles innervated by them.

In cases of quantitative changes in the excitability of the nerves and muscles which occur with slight injuries to the nerve trunks, a greater force of stimulation is necessary to achieve muscle contraction than in the norm. The form of the muscle contraction and its duration remain unchanged.

All the authors using clinical electrodiagnostics stressed the value not of quantitative, but of qualitative changes in the excitability of nerves and muscles in response to the application of two types of electrical stimulation (faradic and galvanic current).

Qualitative changes in electro-excitability are already observed with the disruption of the structural integrity of a terminal motoneuron, and excitability by faradic current is the first to suffer. The latter is explained by the fact that the damaged nerve loses its ability to react quickly to rhythmic impulses of induction current, since for the pathologically changed nerve they now become too short./107

The degree of pathological shifts in excitability depends not on the level at which the denervation took place -- at the spinal cortex level, in the area of the anterior horns of the corresponding sections of the spinal cord, or finally along the course of the peripheral nerve trunks. It is important that in all cases there will be a disruption of the "trophic unity" of the motoneurons, which will entail the degeneration of the peripheral nerves and as a result of this, the complete absence of electro-excitability and conductivity along the course of the given nerves.

As a result, characteristic indicators of reactions of muscular degeneration will be manifested on the part of the corresponding skeletal muscles, evidenced in their full degree only with severe injuries to the peripheral neuron and not occurring with other localizations of the pathological process in the nervous system which do not affect the terminal motor neuron. Thus, the basis for qualitative changes in the reaction of muscle tissue to direct (stimulation of the muscle itself) and indirect (stimulation of the nerve) stimulation by galvanic and faradic current is the reaction of muscle degeneration. It facilitates establishing a differential diagnosis between injury to the peripheral motoneuron and supranuclear traumas.

According to the laws of classical electrodiagnostics, the reaction of muscular degeneration must in its full form be characterized by the following indicators:

1. The absence of nerve trunk excitability to faradic and galvanic current.

2. The absence of muscle excitability to faradic current with retention of muscular reactions to galvanic stimulation.

3. The displacement of the "locomotory point" of the muscle in a longitudinal direction (closer to the tendon).

4. Muscular effect takes place not only with momentary switching of current, but also with its gradual growth, continuing for the entire period of current passage (reduction of accomodation to the electrical stimulator).

5. Distortion of the formula of muscular contraction (anodal shorting becomes greater than cathodal shorting).

6. Contraction of the muscle in response to galvanic current has a flaccid, "worm-like" character with a prolonged latent period, with an extended ascending and particularly descending phase of muscle contraction.

The most constant indications of muscle denervation are considered by clinical electrodiagnostics to be: 1) complete absence of nerve excitability, 2) loss of faradic excitability of the muscles, 3) a flaccid, "worm-like" character of weak muscular contraction.

The listed indications of muscular degeneration were established with complete muscle denervation. However, in cases of lighter or partial trauma to the peripheral nerve, partial reaction of muscular degeneration was noted, when stimulation from the nerve evokes a normal contraction curve and the difference consists only in the quantitative reduction of excitability.

The task of the present work does not include a detailed analysis

of all the positions of electrodiagnostics. We must, however, note that the state of galvanic and faradic excitability of muscles attached to the damaged nerves is subject to considerable fluctuations: it /108 is sometimes increased, sometimes decreased, and in other cases remains within the limits of the norm. In connection with this, we indicated the inadequacy of reactions of muscle degeneration in solving the problem of severity of nerve damage, since even with complete anatomical nerve severance, the muscle degeneration indicated above is not found in all cases (P. K. Anokhin, 1943; Yu. M. Uflyand, 1945). The diversity and multiplicity of indicators of complete and partial reaction of muscle degeneration, the stressing by each author of some single aspect which seems to him the most important and the most fully reflective of the functional state of the neuro-muscular apparatus, the absence of a precise physiological evaluation of the stimulation itself -- all these factors hinder the widespread application of electrodiagnostics in clinical practice.

Without speaking of the absence of precisely graduated and standard unit of measure of electrical excitability used by all researchers (frequency, duration of individual impulse), the most important disadvantage of the method of electro-excitability is the impossibility of clarifying the dynamics of the pathological process through its application, since there is no correspondence between a certain stage of degenerative changes in the nerves and muscles and the appearance of one or another indication of the degeneration reaction. This is precisely why the most authoritative authors stressed the most important significance not of the level of electrical excitability (changing, along with everything else, also with the resistance of skin coverings), but of the character of the contractive effect of the muscle. The indicator of the functional condition of the neuro-muscular apparatus from this standpoint is the rate of passage of the contraction in time.

Depending on the rate of passage of the muscle's contractive effect under conditions of trauma and degenerative processes, in some cases singular or rhythmic electrical stimulation will cause a muscle

contraction which is normal in amplitude and which proceeds rapidly. In other cases, the contraction will be weak, low in amplitude, extended in time, with delayed consequences and a prolonged latent period. In other words, the time factor takes on the leading role in the development of new methods of electrodiagnostics. It is the evaluation of the leading role of this factors which must be the basis for selecting the method of development and the form of the response.

The most important significance of the time factor for the evaluation of physiological properties of stimulated tissues was first proven by the leading Russian physiologist N. Ye. Vvedenskiy in his research. From the works of N. Ye. Vvedenskiy (1886, 1901), which have become classical in neuromuscular physiology, we know that every tissue is characterized by its time for the passage of individual stimulation impulses in the series of tetanic rhythmic stimulation. In other words, each tissue in a unit of time is capable of reproducing a certain number of conclusive singular stimulation "seizures". While N. Ye. Vvedenskiy was engaged in the study of the time for the course of rhythmic impulses in the natural series of tetanic stimulation, foreign authors (Gorveg, Veys, Lapik) studied the significance of the time factor for the emergence of a singular wave of excitation and introduced the concept of chronaxy. Although chronaxy does give a fuller understanding of the functional properties of the stimulated tissues as compared with the standard determination of galvanic excitability, it has many inherent shortcomings which have a decisive significance, particularly in the case of testing the injured nerve. Aside from the threshold of galvanic excitability (rheobase), the /109 change the minimal time within which the current equal to the doubled rheobase can cause the threshold effect must be considered.

Difficulties with precise diagnostics of the degree of injury to the peripheral nerve forced physiologists working in neurological clinics and specialized hospitals to seek new, more complete and comprehensive methods of electrodiagnostics which corresponded to the high level of developing theoretical knowledge. This is how modern clinical chronaximetry arose. Chronaximetry makes it possible to

measure in precisely dosed values (in milliseconds) the speed of emergence of excitation in the studied tissue and at the same time to judge the level of galvanic excitibility (rheobase). Also, thanks to the introduction of shunt resistance into the stimulating current circuit, the value of changing resistance of the skin coverings is excluded to a certain degree, which makes it possible to determine chronaxy in different patients under identical conditions of initial resistance. As a result of all these advantages, chronaximetry has become widespread in nerve clinics as the most perfected method of electrodiagnostics. The military situation required the introduction of chronaximetry into hospital practice. Soviet physiologists conducted a particularly great number of chronaximetric studies during the years of the war at neurosurgical base hospitals. Much work on the study of chronaxy under various forms of wartime trauma to the peripheral nervous system was performed in the years of the Great Patriotic War at the Leningrad Neurosurgical Institute (P. O. Makarov, M. E. Kolik), at the Neurological Institute of the USSR Academy of Medical Sciences (N. I. Grashchenkov, I. G. Fel'dman, M. G. Ignatov), and at the electrophysiological laboratory of the Botkin Hospital (L. I. Il'yina).

As we see from that which has been presented, our country's physiology and clinical neurology made particularly widespread use of the method of electrical stimuli for determining the speed of conducting stimuli along nerves and muscles, the degree of excitability of injured nerves, etc. As a result of all these studies, extensive material has been accumulated which partially aided in clinical studies. But for the most part in those cases where there was a question of chronaximetric studies, it usually contradicted them.

We may indicate such large collectives of physiologists as the Scientific Laboratories of A. N. Kabanov, A. N. Magnitskiy, P. O. Makarov, Yu. M. Uflyand, and others. Among the neurological studies we must note the works of S. N. Davidenkov, V. K. Khoroshko, L. G. Chlenov, N. V. Shubin, and numerous others.

All the experience of the indicated laboratories and of individual scientists cannot be summarized into a single whole, since the difference in principles taken as the basis for the studies had different effects both on the results of these studies and on their interpretation.

This is why it is now necessary to present those principle conclusions which must aid in orientation in the accumulated material and to determine the direction of further research.

From this standpoint, the basic data of this work, obtained primarily at the Institute for Neurosurgery imeni Akad. N. N. Burdenko represent the conclusions drawn from the application of the electrodiagnostic methods.

The correct evaluation of electrodiagnostic indicators could only arise thanks to the extensive experience of numerous research collectives accumulated during the Great Patriotic War, and therefore, naturally, represents a synthesis of this experience. /110

Yu. M. Uflyand, D. A. Markov and others, who developed normal standards for chronaxy in man and the limits of their normal fluctuation for various groups of skeletal muscles, showed that the degree and fluctuations in chronaxy are variable. Thus, even the amplitude of normal fluctuations in muscles of the upper extremities, according to Burgin'yon, fluctuates from 0.8 to 0.28 milliseconds, and according to D. A. Markov -- from 0.12 to 0.46 milliseconds.

During 1942-1945, the authors conducted studies of nerve and muscle chronaxy in over 700 cases of nerve trunk damage in the upper and lower extremities, and noted a wide range of chronaxy fluctuations. Of 700 patients, approximately 350 had wounds to the upper extremities with damage to the radial, median and ulnar nerve in various combinations. Eighty patients had wounds in the area of the brachial plexus, while the rest had injuries to the lower extremities with damage to the branches of the sciatic nerve and more rarely to the femoral nerve.

It was established that the nerve must be approached micro-physiologically, i.e., it must be represented as a complex formation in which the component parts (the individual nerve fascicles and even the nerve fibers) have a different tolerance to the effect of a traumatic agent.

With partial injury to the nerve and development of subsequent cicatrical compression processes, various fibers will always be subject to the effects of direct mechanical action. These fibers will suffer depending on their resistance and, of course, depending on the level of trauma.

After the electrophysiological analytical studies of the last two decades there is no reason to believe that excitability and chronaxy of nerve fibers making up the nerve trunk are the same even in a healthy person. Moreover, with damage to a nerve, we may presume the most varied combinations of relationships between healthy and traumatized nerve fibers.

If the individual nerve fibers (A, B, and C) are distinguished by the difference in their excitability and chronaxy, then in determining the rheobase and chronaxy in threshold values of excitability and impulse duration, these parameters are factually established only for those fibers which have the highest excitability and the shortest chronaxy.

The excitation or non-excitation of each individual fiber depends also on whether or not the current strength and duration of its impulses will be sub-threshold or super-threshold in respect to the excitability and chronaxy of this fiber. Consequently, in determining chronaxy it is necessary to deal not with the nerve trunk as a whole, but with a certain part of it. The number of reacting fibers in each individual case depends not only on the current voltage and duration of its impulses, but also on the anatomical location of the nerve fibers in respect to the active electrode, i.e., on the resistance

of the tissues and membranes between the electrode and the nerve fibrills.

The works of P. K. Anokhin showed that in nerve trunks where the fibers run in more or less separate fascicles to the innervated muscles, the stimulus does not encompass the entire nerve, but only individual nerve fascicles. As a result, a single displacement of stimulus electrode applied to the locomotory point of the nerve may cause the contraction of other muscles in another zone of innervation. In this case there is a sharp change in the values of the rheobase and chronaxy, which are taken by numerous authors as the rheobase /111 and chronaxy of the "nerve trunk", although the greatest part of the fibers in its composition may be degenerated as a result of partial trauma to the given nerve. It is because of these concepts that the expression "chronaxy of the nerve trunk" is essentially incorrect.

Moreover, in chronaximetric studies it is necessary to consider exactly which muscle is contracted with stimulation of the traumatized nerve. In other words, which muscle is the indicator in the measurement of chronaxy of a given nerve. This augments chronaximetry, since it clarifies the question of specifically which nerve fascicles the electro-excitability and chronaxy is being determined for in each individual case.

The obtained data of galvanic excitability, chronaxy and volume of movement must be compared with the same data obtained by studying the healthy extremity. The determination of chronaxy and volume of movement not only on the injured nerve, but also on the healthy one, with their subsequent comparison, makes it possible to more precisely establish the degree of loss of locomotory function with partial injury to the peripheral nerves.

Judging the complete anatomical severance of a peripheral nerve on the basis of clinical investigation alone is made difficult in a number of cases, since up to the present time there is no such method which would indicate anatomical nerve severance with absolute certainty.

The vascillation of the neuropathologist in pronouncing a diagnosis of complete nerve severance may evidently be explained by the almost identical functional condition of the peripheral segment and the muscles which correspond to it, which occurs with anatomical severance as well as with total functional blockage without anatomical severance, when as a result of the effect of pathological factors the nerve loses its capacity for conducting impulses (random and artificial, caused by electrical stimulation). Considering this fact, with any form of gross functional blockage with complete absence of electrical excitability and conductivity resulting not only from anatomical severance, but also, for example, from significant cicatrical compressions, surgical intervention on the nerve will be necessary.

Since the final answer to the question of the character of surgical measures may arise only during the operation, it is specifically at this stage that electrophysiological study with consideration of all the specifics of pathogenesis of the nerve trauma may render the greatest aid to the neurosurgeon. Even in the practice of an experienced neurosurgeon there may be such cases when at the operating table there may arise doubts in the selection between radical and palliative intervention on the nerve trunk.

It should be kept in mind that the pre-operative chronaximetric study may find the absence of electrical excitability and conductivity not only with anatomical severance of the nerve, but also with gross cicatrical injuries, as well as with nerve compression which occurs after partial but gross injury to the nerve trunk. However, on the operating table in the latter case it is possible to establish a certain residual conductivity by stimulating the exposed nerve with electrical current. In such cases, the consultation of the surgeon with an electrophysiologist is particularly important.

The standard, most widespread "electro-conductivity test" of the exposed nerve performed in operating rooms may place the neurosurgeon into an even more difficult position. The fact is that the verification of the presence of electrical excitability and the possibility of /112

determining chronaxy speaks only of the condition of the remaining part of the fibers, i.e., of the degree of their excitability. However, it says nothing of the number of remaining fibers in the nerve, and therefore does not give the surgeon a basis for selecting radical intervention. If, upon stimulation of the exposed nerve by electrical current above the point of trauma the surgeon notices contraction of some muscle in the innervation zone of the stimulated nerve, he concludes that the nerve conducts the stimulation through the damaged section and therefore, rejecting radical operation, he limits himself to neurolysis, which turns out to clinically ineffective.

The negative results after neurolysis operation are explained, evidently, in a number of cases by the fact that the nerve was "spared, despite the very insignificant residual conductivity and the small portion of the preserved nerve fibers, which are incapable of ensuring the restoration of self-sufficient nerve functions. Therefore, the surgeon may have substantiation to solve the problem of whether to perform resection of the injured nerve section or to limit himself to neurolysis only after such an investigation which is specially conducted to answer the question of the form of necessary operative intervention in each individual case.

The chronaximetric method, while it gives some understanding of the individual most excitable trunk fibers, does not characterize the condition of the nerve trunk as a whole. It is specifically this feature of the chronaximetric method which limits its significance for clinical practice and makes it inapplicable for many cases of nerve trunk trauma.

The physiologist's conclusion, which he draws on the basis of studying the excitability of the individual nerve fibers, gives little to practical neurosurgery, which is associated with intervention on the nerve trunk as a whole. The injured nerve has a great variance in excitability of the individual fibers and, consequently, the chronaxy of the most excitable fiber is clinically the least characteristic of the condition of the nerve as a whole.

At the operating table, the neurosurgeon must always decide which operative intervention to perform in the given case. It is quite evident that the decision of the neurosurgeon here is in direct dependence on the degree to which the anatomical continuity of the nerve trunk has been retained. If 4/5 of the nerve has been severed and only 1/5 remains which is capable of conducting stimuli, then the resection of the injured section and nerve trunk suture gives greater chances for the successful regeneration of the trunk as a whole. On the other hand, if 4/5 is retained and only 1/5 of the nerve is damaged, there is every basis for performing partial resection and suture of only the resectioned nerve segment.

## The study of nerve function by the method of "volume of movement" description

This form of study was introduced by us at the Institute of Neurosurgery imeni acad. N. N. Burdenko for orienting the neurosurgeon in the actual condition of the nerve trunk as a whole. Basically, this research was conducted in many hundreds of cases of operations with nerve exposure. It is specifically under these conditions that the neurosurgeon must most often vascillate in his selection of the method of operative intervention. Operations on nerve trunks performed with the application of electrical current for determining the volume of movement convinced us that the surgeon operating on the nerve must hold a scalpel in one hand and an electrode from an electrodiagnostic device in the other. Only with this condition is he able to obtain /113 a clear picture of which nerve he is dealing with. Operative intervention performed on the basis of visible concepts of the extent of the trauma often leads to error.

The study of the exposed injured nerve is conducted in the following order: first the rheobase and chronaxy are determined for a description of the condition of the retained group of fibers, then the volume of movement is tested. Gradually increasing the voltage of the stimulating current to that maximally possible for the given patient, an evaluation is made at each stimulus increase of the growth in muscle contraction and inclusion of new muscles into the reaction.

If we compare the course of the gradual inclusion and intensification of muscle contraction with the growth in contraction with the stimulation of a normal nerve, then we may obtain an understanding of the volume of the locomotory functions which have been retained in the damaged nerve.

Here we must note that the given method of nerve study, which has been successfully applied in numerous nerve operations, requires from the surgeon a knowledge of the innervation zone for each given nerve. He must have a precise understanding of the relation of each individual muscle in the extremity to the nerve being operated.

Naturally, in solving the problem of the necessity for resection of the damaged nerve section, electrophysiological study must be combined with the visual observations of the surgeon. Visual observation and palpatory data make it possible to obtain an understanding of the macroscopic changes in the structure of the nerve trunk, while the electrophysiological study of the damaged nerve speaks of the number of nerve fibers which have preserved their conductivity for electrical impulses.

To illustrate the study of the volume of movement during an operation we will present two examples.

Wounded patient Ab-n. Pre-operative diagnosis: absence of electrical excitability and conductivity along the course of the left ulnar nerve due to its gross traumatic injury at the level of the central third of the shoulder. Operation performed 10/29/1943.

By means of comparing gross macroscopic changes (intra-trunk neuromas and the presence of scars around the nerve) and results of electrophysiological testing (a significant reduction in electro-excitability of the exposed nerve and limitation in movement as a result of the reduction in volume of contractive muscle of the thumb and absence of inclusion of new muscles into the reaction with increased force of stimulus), it was determined on the operating table that most of the fibers in the trunk of the left ulnar nerve (the functionally most important part) had been severed. Only a limited number of fibers was preserved, innervating the m. adductor pollicis. Resection of the damaged

area was performed and both renewed ends of the nerve were sutured.

Wounded patient B-ov. Pre-operative diagnosis: reduction in electro-excitability of the right median nerve due to its partial traumatic injury in the central third of the shoulder. Operation performed 12/8/1943.

In this case, with increased voltage of the stimulus current, a gradual inclusion of an ever greater number of muscle groups was noted in almost the same sequence as with stimulation of a normal nerve.

The diagnosis established on the operating table: retention of conductivity and electrical excitability in almost all the fibers comprising the right median nerve, as well as the absence of its macroscopic changes and palpatory data on intra-trunk neuromas made it possible to be limited to neurolysis in this case.

| Nerve studied | Current voltage in V | Indicator (reacting muscle) | Intensity of contraction | Notes |
|---|---|---|---|---|
| Wounded patient Ab-n. Left ulnar nerve, upper point | 30 | No effect | | Threshold of electro-excitability of normal exposed nerve 2-4 V |
| | 50 | " " | | |
| | 65 | " " | | |
| | 75 | M. adductor pollicis | + | |
| | 85 | Same | ++ | Further increase in the voltage of the stimulating current is impossible due to the pain reaction of the patient |
| | 95 | " | ++ | |
| | 120 | " | ++ | |
| Wounded patient B-ev. Right median nerve, upper point | 15 | No effect | | |
| | 30 | " " | | |
| | 40 | M. flexor digitorum sublimis | + | |
| | 50 | M. pronator teres | ++ | |
| | 70 | M. flexor carpi radialis | + | |
| | 80 | Same | ++ | |
| | | " | ++ | |
| | 90 | " | +++ | |
| | | " | +++ | |
| | | " | +++ | |

Designations for table: + barely noticeable threshold contraction; ++ more intensive, but still weak contraction; +++ contraction of moderate amplitude; ++++ contraction of normal amplitude.

An examination and comparison of individual cases showed that it is impossible to give a standard scheme suitable for all cases of injuries to the peripheral nerve, since it is impossible to foresee the combinations which may be observed on the operating table.

Positive results will be obtained only when all tests are considered performed before the operation as well as during the operative intervention. As concerns the chronaximetric evaluation of the post-operative dynamics of restoring electro-excitability and conductivity, the relationships taking place here are more complex.

At the beginning of the regenerative processes, when the patient is barely beginning to note the restoration of sensitivity in the zone of innervation of the sutured nerve, electro-excitability and conductivity are, as a rule, absent. With restoration of the arbitrary locomotory function of the operated nerve, the appearance of electro-excitability of the muscles is usually noted, and their chronaxy is shortened with progression of the motor function. It is necessary to wait much longer for the restoration of indirect excitability of these same muscles with their already restored arbitrary motility. In other words, with electrical stimulation of the nerve, the stimulus does not reach the muscle, despite the fact that the transmission of willed motor impulses is obviously a result of nerve regeneration. This situation may evidently be explained by the greater adequacy of the arbitrary willed impulses as compared with artificial electrical impulses. In the process of regeneration, natural arbitrary impulses by their force, frequency and duration are more optimal for the regenerating nerves than are the artificial jolts of galvanic or condenser current. On this question, the physiology of regenerating /115 peripheral nerves may be successfully developed only by considering the specifics of cortical regulation of peripheral nerve functions in accordance with the studies of I. P. Pavlov.

The method of study using graduated frequency of stimuli

Divergences between clinical data and electrophysiological research are found not only with the regeneration of the nerve after operation, but also in the pre-operative period, when often the level of chronaxy does not reflect the degree of damage to the peripheral nerve.

The basic disadvantage of chronaximetry is the fact that it reflects the capacity of the neuro-muscular apparatus to respond to singular stimulus of a certain duration, since chronaxy is determined with the aid of singular electrical stimulus. In the nervous system, signalling is accomplished by rhythmically arising stimulus impulses. Consequently, an evaluation of the conductive properties of the tissue according to physiological lability (i.e., according to the ability to react to rhythmic impulses of various frequency) is more adequate than an evaluation of conductivity based on any parameter of a singular wave of stimulation.

In connection with this, a method was developed at the Institute of Neurosurgery imeni Acad. N. N. Burdenko for more complete physiological diagnosis of nerve degeneration based on the study of the reaction of the nerve and muscle to repeated stimuli of graduated frequency (1943).

The classical experiments of N. Ye. Vvedenskiy (1886, 1901) brilliantly proved the dependence of neuro-muscular apparatus reactions on the frequency of entering rhythmic impulses of electrical current. At the present time, a huge amount of factual material has been collected which demonstrates that every tissue has its optimum and pessimum reaction. An optimal stimulation evokes a series of such rhythmic impulses which, by their amplitude, frequency and duration and best "mastered" by the given nerve and, reaching the muscle, lead to its maximal contraction. If, however, the impulses which rhythmically follow one another exceed the optimal "flow" in their intensity, frequency and duration, then such stimulation has an inhibiting pessimal effect and causes reduction in muscle contraction.

A special device was constructed which allowed the clinical application of the methodology of studying the neuro-muscular apparatus developed by the school of Vvedenskiy-Ukhtomskiy for experimental work on a neuro-muscular preparation from animals. Using rhythmic stimuli for a description of the functional condition of the neuro-muscular apparatus of man, we retained the basic methodological requirements of N. Ye. Vvedenskiy in conducting these studies, namely:

1) the possibility of rapid and precise gradation in the frequency of stimuli over a wide range (ranging from 1 to 1,000 impulses per second);

2) the implementation of objective registration of the results of rhythmic stimulation of nerves and muscles by means of miographic recording of the muscular contractions on a moving kimograph tape.

The obtained myograms show that the optimal rhythm of stimulation for normal human nerves is a rhythm of 50-150 impulses per second. /116 When the stimulus frequency is increased to 500-600 impulses per second, under normal conditions the muscles continue to give optimal contractions (due to the inclusion into the reaction of more and more new groups of nerve fibers, which ensure the maintenance of normal tetanus).

The muscles react differently with trauma to their innervating nerves. In these cases, the "flow" of optimal frequencies is reduced, and the previous stimulus rhythm of 200-300 impulses per second already becomes pessimal, since it leads to a reduction in the muscle contractive effect due to excessive frequency of stimulation.

In cases of partial injury to the nerve trunk, even with low frequencies of stimulation, it is possible to discern pathological shifts in the functional condition of the neuro-muscular apparatus which are not discovered by the chronaximetric method. The electroexcitability and chronaxy of the nerves and muscles remained within the limits of normal fluctuations, while myograms showed an increase in the capacity for summation of stimulation.

In normal muscles, the transition from singular contractions to a merged tetanic contraction (through a stage of toothed tetanus) takes place with a frequency of 15-20 impulses per second. When the nerve is injured, due to the delay in time of each singular contraction, the merging into a solid tetanus is noted on myograms already at a stimulation frequency of 4-6 impulses per second. Even the data presented is sufficient to conclude that there is a reduction in the lability (functional mobility) of muscles after trauma to the nerves, a reduction in the capacity to react to rhythmic impulses of a normal frequency for healthy muscles, and that there is a delay in the time of individual muscular contractions.

Using the method of rhythmic, graduated muscle stimulation, we may gain an understanding also of the restorative processes which take place in the muscles, particularly in the synapses, as the nerves undergo regeneration and the nerve fibers grow into the muscle.

Serving as an illustration of this are two myograms of patient N: 8 months and 15 months after a nerve suture operation (fig. 46). From a comparison of both myograms it is completely evident that there is an increase in muscle lability in the second study. This, undoubtedly, is associated with the fact that regenerating nerve fibers have begun to grow into the muscle.

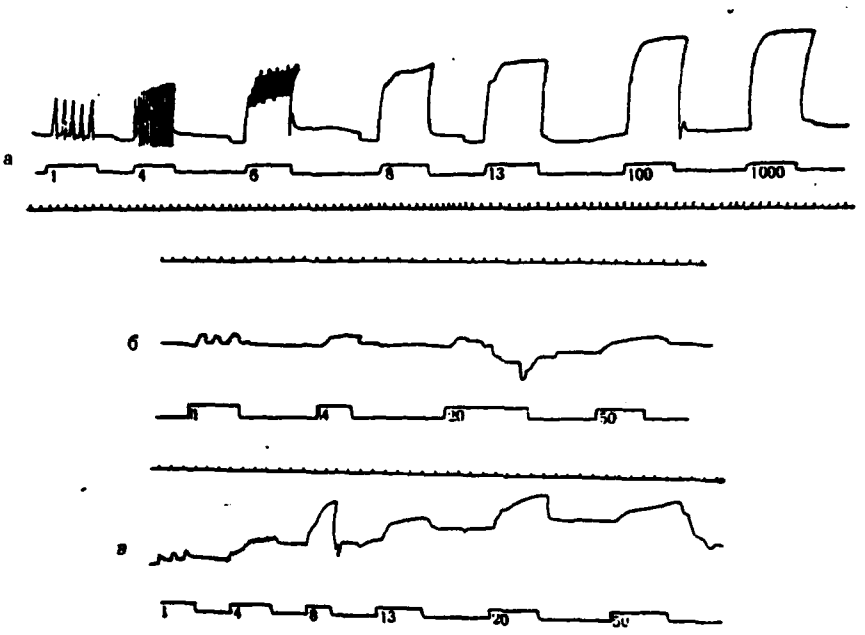
The higher level of muscle lability in myogram c is indicated by the increase in the pessimum threshold, the greater amplitude of the contraction itself, and the presence of peaking at a frequency of 4 impulses per second. Consequently, as the nerve fibers regenerate, the functional mobility of the muscles gradually increases.

Studies of the reactions of muscles to rhythmic graduated stimuli may significantly replace the noted inadequacy of the method of classical electrodiagnostics, and specifically the impossibility to perform a differential evaluation of the functional state of the muscles at various periods after denervation.

All the data presented above allow us to conclude that the methodology used previously was clearly insufficient for the pronouncement of a comprehensive diagnosis. Used for the most part for faradic stimulation is an induction coil, which usually gives the same unchanged frequency of induction impacts -- approximately 80-100 per second, i.e., the absence of muscle reaction to faradic current is a simple result of a randomly selected stimulation frequency. With /117 the generally accepted methodology of faradic stimulation, the denervated muscle is given such a stimulation frequency which is already pessimal for the given level of degenerating muscle. The fact is not considered that a simple reduction in the frequency of faradic current from 80 to 30-40 impulses per second would give a normal tetanic contraction. This is particularly important since that anatomically severed nerve degenerates in the first 10-15 days, while the distrophic processes in the muscle extend for considerable time periods. However, with an induction impact frequency of 80-100 impulses per second, as a relatively high frequency, muscle contraction will be absent in the first week after the peripheral nerve injury as well as 2-3 years later. Using rhythmic stimulation which is precisely graduated by frequency (from 1 to 1,000 impulses per second), it is possible to /118 attain an additional indicator for evaluating the degree of muscle degeneration at any given moment.

An even more in-depth analysis of the physiological properties of muscle tissue at various times after peripheral nerve injury is possible with the study of muscular potentials (V. S. Rusinov, S. A. Chugunov).

Electromyogram readings with arbitrary contraction of a partially degenerated muscle (with partial nerve damage) shows a reduction in the rhythm of muscular potentials. The continuity of the muscular impulsation is lost. It was demonstrated that the most characteristic trait of an electromyogram, particularly of the general digital flexor with partial loss of motor function of the median and ulnar nerves resulting from trauma is a sharp reduction in the amplitude of active currents and a significant overall reduction in their rhythm. Depending on the

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Myograms of contractions of a normal (a) muscle and partially degenerated (b and c) muscles after damage to the peripheral nerve.

Myogram a. A normal myogram of the abductor muscle of the thumb in response to rhythmic graduated stimuli (from 1 to 1,000 impulses per second).

Myogram b. Direct stimulation of the thumb abductor muscle 8 months after suture of the median nerve. Top line -- time marger (once per second). Center line -- myogram in response to rhythmic stimuli. Lower line -- stimuli marker. The elevation in the line corresponds to the moment of current application, the descent of the line -- to the moment of turning off the stimulus current. The numbers at the bottom indicate the frequency of stimulation. The intensity of stimulation was 220 V. With stimulation once per second there are recorded weak amplitude singular contractions extended for almost a second. At a frequency of 4 impulses per second there was already a merging into a merged tetanus, which is also noted with a very low amplitude and a long latent period.
At a frequency of 20 and 50 impulses per second there are extended, weak tetanic contractions.

Myogram c. The myogram of the same thumb abductor muscle in the same patient 14 months after suture of the median nerve, and with the same intensity of stimulation (200 V). With a stimulation frequency of 4 impulses per second, a peaked tetanus is already registered. With gradual increase in frequency, the recording shows merged tetanuses of greater amplitude than the tetanus at the same intensity and frequency of stimulation presented in myogram a.

degree of damage to the nerve trunks, the overall rhythm of the /118 muscular action currents may fluctuate. If the rhythm of the electromyogram for the healthy arm with willed muscle contraction can serve as an indicator of the central rhythm, then with partial injury to the neural conductors the rhythm of the electromyogram is to a greater degree an indicator of the condition of the very center of injury in the nerve trunk. With injury to the human peripheral nerves, for determining disruptions in sensitivity it is still necessary to use methods which are based more or less on the subjective indications of the patient. Electrophysiology has performed detailed studies under experimental conditions of the function of afferent conductors with tactile, pain, and proprioceptive stimulation of the corresponding receptors, and therefore it is possible to use recordings of action currents in judging the conductivity of the corresponding afferent conductors. One of the tasks awaiting electrophysiologists engaged in the study of the peripheral nervous system is the development of the most suitable methods for recording action currents of human nerve trunks through the skin, particularly for the purpose of objectively judging the retention of the conductivity function of afferent fibers in the nerve trunk.

## SPECIAL SECTION

## CHAPTER I

## THE CLINICAL TREATMENT AND DIAGNOSTICS OF FIREARMS WOUNDS TO INDIVIDUAL PERIPHERAL NERVES

### The clinical treatment and diagnostics of injuries to the nerve trunks of the upper extremities

Injury to any peripheral nerve is characterized first of all by /119 central localized symptoms, which primarily determine the basic clinical syndrome.

With complete severance in nerve conductivity, sharp disruptions are noted in all its functions in the area innervated by the given nerve -- there are disruptions in locomotion, sensitivity, reflexes, trophics and other vegetative functions are disrupted. However, as a rule, with isolated injury to only one nerve, with the neighboring nerves remaining intact, all these manifestations of loss were expressed to a much lesser degree. The experience of the war shows that the greatest manifestations of loss were noted with the simultaneous injury of two or more peripheral nerves. Thus, according to the materials for the development of illness histories, locomotory disruptions with combined injuries to the nerves of the upper extremities were noted in 98.7%.

The radial nerve. According to the materials for the development of illness histories, firearms wounds to the radial nerve were noted in 25.4%. Of these, 15.5% were isolated, 5.4% were combined injuries to the radial and median nerve, 5.0% were combined injuries to the radial and ulnar and median nerves, and 1.9% were combined injuries to the radial and ulnar nerves.

According to the materials of personal observations, isolated injuries to the radial nerve were noted in 166 cases. Of these, in

138 cases (i.e., in the overwhelming majority) there was injury to the shoulder, primarily in its central third. The course of the nerve, which spirals around the brachium in this area, makes the frequency of combined injury to the radial nerve and the brachium quite understandable. Fracture of the brachium was found in over a third of the patients with injuries to the radial nerve. After injury, typical locomotory disruptions were usually manifested, expressed in one degree or another: disruption of hand and finger extension, and with a high level of injury -- supination and extension of the forearm. The function of the triceps muscle with a high level of injury to the radial nerve did not disappear fully (in the opinion of N. B. Chibukmakher, the triceps muscle is additionally innervated by the ulnar nerve). All patients with complete disruption in the conductivity of the radial nerve exhibited an absence in the abduction and adduction of the hand, which was particularly evident when the hand was lowered.

With wounds to the forearm where, as we know, the radial nerve is divided into separate branches, there was often observed isolated paralysis of individual muscles innervated by the radial nerve (the /120 absence of flexion in the fingers with retention of the extensor functions of the hand, loss of isolated extension of the thumb or index finger with retention of overall extension of the fingers).

Case histories, as well as notes in illness histories recorded at early stages of evacuation, prove that immediately after the wound was sustained, locomotory disruptions occurred in the muscles innervated by other nerves (for example, absence of flexion in the hand, fingers). However, even in a later period (3-4 months after the wound was sustained), a disruption was noted in flexion, and particularly in abduction and adduction of the fingers, i.e., there was a disruption in the function of muscles innervated by the median and ulnar nerve. The experience of the Great Patriotic War showed that these disruptions were noted much more frequently than was previously assumed.

The mechanism of combined locomotory disruptions with injuries

to the radial nerve have not been fully clarified. In the opinion of B. S. Doynikov, as a result of the constant flexion of the fingers and hand there was a gradual shortening of the flexors, which entailed the disruption of their function. Constant flexion of the primary phalanges creates unfavorable conditions for the functioning of interosteal and vermicular muscles and leads to the disruption of abduction and adduction of the fingers. In the opinion of S. N. Davidenkov, with exclusion of the extensors, there are significant changes in the complex function of the hand and particularly the fingers, which may be expressed in the function of the muscles innervated by the ulnar and median nerve.

In analyzing the materials of personal observations concerning 65 operated patients with injuries to the radial nerve, it turned out that the disruption in flexion, abduction, adduction of the fingers, as well as poor performance on the test for thumb opposition, were more sharply expressed in those patients whose nerve trunk was found to be macroscopically intact during the operation, and surrounded by scars with intra-trunk cicatrical changes. Thus, conditions were present for the irritation of the damaged nerve trunk, which may lead to inhibition of the antagonists and synergists through the segmentary centers.

We must stress once again that with injury to the radial nerve, under-estimation of the possibility of functional disruptions in muscles which are not directly related to the innervation of this nerve led to an incorrect diagnosis and treatment.

With complete disruption in the conductivity of the radial nerve, 1-2 months after the wound was sustained there was usually a clear manifestation of atrophy of the extensors, particularly in the forearm. This atrophy was usually combined with the presence of a degenerative reaction.

The absence or reduction in the elbow extension reflex, even with

a high level of injury to the radial nerve, was noted very rarely. In wounded patients having a flexion contracture, a tap with a hammer on the triceps muscle tendon was often accompanied by flexion of the forearm instead of extension. As concerns the carpo-radial reflex, it was not disrupted only in singular cases. Often it was not evoked, but more often in testing this reflex, there was a loss in flexion of the forearm with retention of supination and flexion of the fingers.

It is customary to believe that secretory, vascular and trophic disruptions with injuries to the radial nerve are temporary indications of its injury. However, we often had occasion to observe edema of the back of the hand, particularly in wounded patients who did not use splints to secure the hand in an extended position. We must also note that with injuries to the lower third of the forearm with involvement /121 of the dorsal interosteal nerve into the cicatrical process or with injury of this nerve in case of fracture of the distal end of the radius, there was often observed edema of the back of the hand in combination with sharp trophic changes (osteoporosis) in the bones of the hand and fingers.

The data on the frequency of sensitivity disruptions with firearms injuries to the radial nerve are contradictory.

Some [authors] believe that sensitivity disruptions with injuries to the radial nerve are observed rarely. In individual cases, sensitivity disruptions were observed with preservation of the locomotory function. Often sensitivity disruptions with wounds to the radial nerve may be manifested only with testing by Beber's circle. I. N. Gorodetskiy, in analyzing diagnostic errors in radial nerve wounds, stressed the frequency of compensation in zones of radial nerve cutaneous innervation by the median nerve. A. I. Geymanovich pointed out that injury to the radial nerve in combination with disruption in the integrity of the brachium is characterized by the absence of sensitivity disruptions. On the contrary, in wounded patients sustaining direct injury to the radial nerve, a loss of sensitivity was often noted.

According to the materials for the development of illness histories, the following relationships of sensitivity disorders were observed with firearms injuries to the radial nerve. (Table 15)

Table 15

The relation of the frequency of sensitivity disorders with injuries to the radial nerve

| Character of sensitivity disruptions | Amount in percentages |
|---|---|
| Hypesthesia | 66.1 |
| Anesthesia | 27.0 |
| No sensitivity disorders | 4.9 |
| Hyperesthesia | 1.2 |
| Soreness with palpation of the nerve trunk | 0.4 |
| Paresthesia | 0.1 |
| Causalgia | 0.1 |
| Phantom pains | 0.1 |
| Combined changes in sensitivity | 0.1 |

In all cases, articulatory-muscular sensation was retained. As concerns vibratory sensation, according to the data of I. Yu. Kokhanovskiy this type of sensitivity was disrupted (reduction on the dorsal surface of the hand, somewhat more sharply expressed in the area of the I and II fingers).

Spontaneous pains are not a constant indication of firearms injuries to the radial nerve. As concerns pains of causalgic character, such cases are described as causuistic. According to the materials of personal observations, complaints of pain were noted in 15.0% of the wounded patients with isolated injury to the radial nerve. Of these, 10.0% suffered from pains of a burning character. Ten wounded patients who complained of pains were subjected to operation: in four of them there was found a severance of the nerve trunk with divergence of the ends, and in five patients there was a "connective tissue strip" between the ends of the damaged nerve trunk. In one patient

the nerve turned out to be scarred. Thus, although pains during injuries to the radial nerve are noted significantly less frequently than with injuries to other nerve trunks, nevertheless they were /122 observed in a significant percentage of cases, even with anatomical severance of the nerve trunk.

The combination of the described locomotory and sensitivity disruptions in the great majority of cases made it possible to establish injury to the radial nerve without particular difficulties. Of the generally accepted tests characteristic for paralysis of the radial nerve, the following turned out to be the most valuable:

1. A typical position of a drooping hand with slightly bent fingers in stepped order; the fifth finger is more bent, the IV finger is bent less, the III finger still less (fig. 47).

2. The absence or weakening of tension in the brachio-radial muscle with flexion of the forearm.

Fig. 47. Wounding of the radial nerve at the level of the shoulder. The hand droops down in the position of pronation in combination with slight flexion of the fingers.

3. Good extension in the end and middle interphalangeal articulations with support of the primary phalanges on the palmar surface.

4. When the hands are placed together and the palms spread apart, the hand and fingers flex on the afflicted side (fig. 48).

Depending on the level of injury to the radial nerve, the clinical picture may vary. With injury to the radial nerve at the level of the upper and central third of the shoulder, the function of the extensors of the hand and fingers was lost. Supination was impossible with the hand extended, flexion of the forearm was partially disrupted due to paralysis of the brachio-radial muscle. Disruption of sensitivity is determined on the dorsal surface of the shoulder, forearm, radial dorsal surface of the hand, and the primary phalanges of the I, II and partially the III finger. With injury to the radial nerve in the upper third of the forearm, the function of the hand and finger extensors was disrupted, with disruption of sensitivity on the dorsal-radial surface of the hand and the first two fingers. With injuries in the lower third of the forearm, the function of thumb and index finger extension was disrupted with disruption of sensitivity on the radial half of the back of the hand and the first two and a half fingers.

An analysis of the course of locomotory and sensitivity disruptions makes it possible in most cases to determine the degree of disruption in conductivity. Considerable difficulties arose in solving the /123 problem of the character of injury. A comparison of clinical data with data found during operation makes it possible to repeatedly ascertain that the symptoms of complete disruption of conductivity may be observed with a macroscopically whole nerve trunk and that, on the other hand, with anatomical severance with divergence of the ends of the damaged nerve, partial retention of sensitivity due to compensation.

With the restoration of the radial nerve, usually the disruption of skin sensitivity on the back of the hand was the first to disappear.

The restoration of the locomotory function was characterized by a weakening of the volume of pronation. It became possible to hold the hand back during extension. Further, there was increase in the

tonus of the supinator and extenders. Usually the first to appear were active movements of the radial extenders of the hand, then -- the general extender of the fingers. The last to be restored were the extenders and abducting muscles of the thumb.

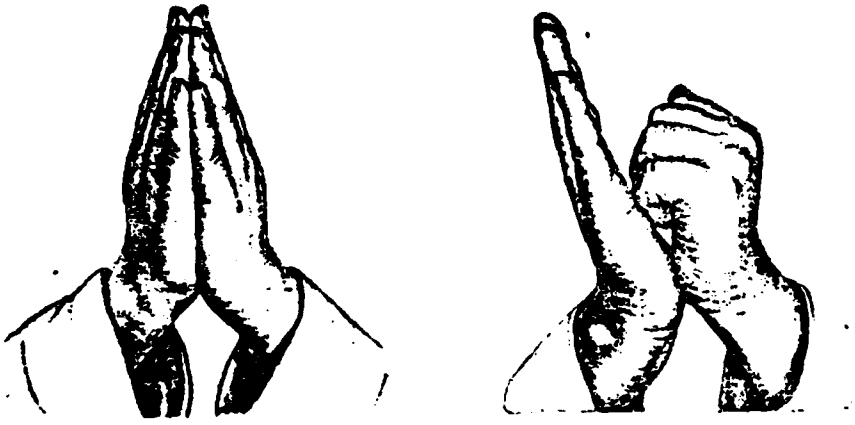

Fig. 48. Spreading the palm resulting from extension in the radiocarpal articulation. Flexion of the fingers is noted on the side of damage to the radial nerve.

A record of the time for clinical restoration of a nerve is particularly important in the period of development of the wound process. This confirms or denies the preliminary diagnosis of paralysis to the radial nerve.

The restoration of movement in 1½-2 months with traumas to the radial nerve indicates a severe contusion, concussion or hemorrhaging in the nerve. The absence of regeneration after 4-5 months indicates the presence of a trauma to the radial nerve, accompanied by its total severance, most often with displacement of the ends. In rare cases, the absence of regeneration after 4-5 months may indicate severe trauma with extensive spread of hemorrhaging over a large extent in the nerve with retention of its anatomical integrity.

The following indicators speak of complete restoration of function to the radial nerve: 1) when the hand is placed palm upward on a table,

the II and V fingers and their and their metacarpal bones touch the surface of the table, while the thumb is extended and abducted outward; 2) with the hand lowered, the fingers and fully extended, the palm /124 is turned forward, and the thumb is abducted. Simultaneously with the restoration of the locomotory function, sensitivity disruptions are evened out. It is necessary to stress that with full restoration of the motor function, hyperpathy may be retained for a long period, significantly reducing the work capacity of the hand. It is usually felt that restoration of function with injury to the radial nerve, unlike other nerves, occurs more rapidly.

The absence of ordinary indications of restoration in conductivity in the course of a relatively long period after injury is not always an indication of a hopeless situation.

Spontaneous pains, as we have already mentioned above, were not a constant indicator of injury to the radial nerve. Usually these pains gradually subsided. However, we have often had occasion to be convinced that these pains may also take on a prolonged character. Since the basis of these pains was often an injury to the cutaneous branches of the radial nerve, whose condition was not sufficiently noted by neuropathologists as well as surgeons, we feel it expedient to focus attention on spontaneous pains in cases of firearms injuries to the radial nerve.

The median nerve. By frequency of isolated injury, the median nerve, according to the data for the development of illness histories, occupied sixth place, which comprises 8.2%. However, its injury in combination with damage to other nerves was noted considerably more frequently in comparison with injuries to other large nerve trunks of the upper extremities (see table 1).

The median nerve, as we know, contains, along with locomotory and sensitivity fibers, a large number of vegetative fibers, which explains the frequent occurrence of vasomotor, vascular and trophic disruptions during injury to the median nerve, particularly in cases where it is not completely severed.

The clinical picture also varied depending on the degree and level of injury to the median nerve. With full disruption of conductivity in the median nerve as a result of its injury at the shoulder or in the upper third of the forearm, pronation of the forearm was disrupted, and partially flexion of the hand. The wounded patient was unable to actively flex the end and central phalanges of the II and III fingers, flexion and opposition of the thumb was disrupted, as well as adduction and abduction of the II and III fingers and extension of the end and central phalanges of these fingers. These locomotory disruptions were usually combined with a clearly expressed atrophy of the muscles in the intumescence of the thumb, as well as the first and second vermicular muscle. Among the sensitivity disorders it is necessary to note anesthesia on the palmar and dorsal surfaces of the end and central phalanges of the II and III fingers, hypesthesia, often with a character of hyperpathy on the palmar surface of the thumb and the radial half of the hand. The articulatory-muscular sensitivity was usually lost in the interphalangeal articulations of the II and more rarely the III fingers.

Vibratory sensation was absent in the end and central phalanges of the II and III fingers, was sharply reduced in the primary phalanges, was less reduced in the thumb, and partially retained in the IV finger and slightly disrupted in the fifth finger.

Injury to the median nerve at the level of the lower third of the forearm was characterized by disruption in flextion and opposition of the thumb, adduction and abduction of the II and III fingers, as well as extension of the end and central phalanges of these fingers. Sensitivity disorders were often expressed more sharply and encompassed greater areas as compared with cases of high injury to the median nerve.

The elbow flexion, elbow extension and carpo-radial reflex, /125 as a rule, turned out to be unchanged. In individual cases (particularly with injuries to the forearm), absence of the carpo-radial reflex was noted, a reduction or loss of its individual components (absence

of pronation or flexion of the fingers). In several wounded patients with causalgic syndrome there was observed an increase in the tendinous reflexes on the afflicted arm.

The incomplete manifestation of the listed locomotory and sensitivity disorders, expressed to one degree or another, is characteristic for partial injury to the median nerve. It is necessary to stress that one of the constant indications of partial injury to the median nerve was the early development of painful rigidity in the radiocarpal, carpo-phalangeal and interphalangeal articulations.

If with full disruption of conductivity of the median nerve there was often observed a typical position of the fingers (absence of flexion in the I, II and limitation of flexion in the III finger) (fig. 49), then with partial disruption in conductivity there was often found a bent hand, half-bent and adducted fingers. Sometimes there was a sharply expressed extension of the hand and fingers: "monkey hand", which is usually considered typical for injuries to the median nerve. The hyperpathic character of sensitivity disorders was observed much more frequently with partial injuries to the median nerve.

In the opinion of B. S. Doynikov, partial paralyses with injury to the median nerve, as compared with injuries to the radial nerve, were observed more frequently. According to the materials of personal observation, injuries to the median nerve with partial disruption in its conductivity were observed in the overwhelming majority of wounded patients. N. A. Iozefovich noted a certain regularity in the relation of loss of zones of sensitivity disruptions in wounds to the median nerve, depending on the side where the injury was sustained. With injuries to the outside part of the trunk in the lower third of the forearm, maximal loss of sensitivity corresponded to the area of the I finger; with injury to the inside section of the nerve trunk, loss of sensitivity in the territory of the III and IV fingers turned out to be most complete.

Fig. 49. The position of the fingers with total disruption in conductivity of the median nerve -- absence of flexion in the II, II and limited flexion in the III finger.

According to the materials for the development of illness histories, with firearms injuries to the median nerve, the following relations of sensitivity disorders were found (table 16).

According to personal materials, a constant indication of injury to the median nerve were vascular, secretory and trophic disorders, particularly in wounded patients with partial disruption in the conductivity of the nerve trunk. Cyanosis and disorders in perspiration (anhydrosis with total disruption of conductivity, hypo- and hyperhydrosis with partial) were often limited to the usual zone of cutaneous innervation.

From the data for the development of illness histories it is evident that with firearms injury to the median nerve, disruption in perspiration was observed in 1.2%. "Sucked fingers" (the terminology of S. N. Davidenkov) with thinning of the skin, disappearance of the folds in the skin, brittle nails with disruption in pigmentation and growth of the subungual bed, peeling, and sometimes also sharply /126 expressed hyperkeratosis with primary localization in the zone of cutaneous innervation of the nerve, osteoporosis of the bones in the

hand and fingers -- all these changes were often found in the wounded patients. Trophic ulcers were observed in singular cases. As a result of burns or frostbite, ulcerations occurred on the end phalanges of the II and III fingers which did not heal for long periods (fig. 50).

Table 16

Relation of frequency of sensitivity disorders with injuries to the median nerve

| Character of the sensitivity disorders | Number in percentages |
|---|---|
| Hypesthesia | 60.6 |
| Anesthesia | 30.7 |
| Causalgia | 2.8 |
| Hyperesthesia | 2.7 |
| Disorders were absent | 2.1 |
| Palpatory soreness of the nerve trunk | 0.5 |
| Paresthesia | 0.3 |
| Hyperpathy | 0.3 |

Fig. 50. Trophic changes with injury to the median nerve with partial disruption of its conductivity.

A number of works were published during the Great Patriotic War which were devoted to vascular changes, changes in the photoreactivity of the skin, the hydrophilic properties of the tissues, and tissue metabolism. All the listed disorders were most expressed with injuries to the median nerve.

According to the materials of personal observations, the most constant indication of injury to the median nerve was pain. When wounded patients were questioned about the sensations which they experienced at the moment the wound was sustained, they often indicated that, along with the disappearance of movement in all or in the first three fingers, there were various sensations of pain, with primary localization in the hand and the fingertips: "the arm was pulled", "the hand felt on fire", "it tore, burned along the palm as if the skin were being torn off", etc. Often there was a sensation of numbness in the hand, sometimes with primary localization in the first three fingers. Along with this, wounded patients constantly complained of pains of various character and various intensity. In over half of the wounded patients these pains bore a burning character, and 25.0% of the wounded exhibited the classical Weir-Mitchell causalgic /127 syndrome.

Of the locomotory tests characteristic for injury to the median nerve, the most valuable for diagnosis were the following:

1. The subject places his hand palm down on a table. The The hand is in firm contact with the surface of the table. In this position, the patient with injury to the median nerve cannot scratch with the index finger (fig. 51).

2. When the hand is compressed into a fist, the thumb does not lie on the dorsal surface of the index finger.

3. The wounded patient cannot touch the end of his thumb to the end phalanx of the index finger.

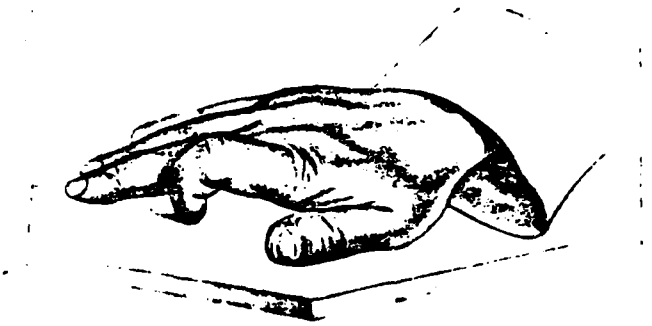

Fig. 51. Test for "scratching" with the index finger for indicating injury to the median nerve.

Considerable difficulties arose in solving the problem of the degree and particularly the character of the injury. Often with a clinical picture of total disruption in the conductivity of the median nerve, only partial injury was found on the operating table, or vice versa, with the presence of indications of partial retention in the conductivity, the nerve turned out to be severed with a large diastase.

The restoration of functions of the median nerve when its ends were touching took place for the most part slowly, and was not always complete. Innervation of the long muscles was usually restored first, and first of all there was a restoration of pronation. Somewhat later there appeared flexion of the index finger and, finally, opposition of the thumb.

Indication of the functional restoration of the median nerve are:

1. Holding an object between the pulp of the thumb, bent at the interphalangeal articulation, and the radial surface of the index finger.

2. Opposition of the thumb in relation to the pulpous area, but not to the radial surface of the ungual phalanx of the V finger.

Often when the locomotory function had already been restored, there was still a prolonged retention of sensitivity disruptions, which could significantly reduce the work capacity of the wounded patient. The following case may serve as an illustration.

Wounded Kh. received neurolysis of the median nerve in the central third of the forearm on 6/27/1942.

Repeated examination of the patient over a period /128
from 1942-1946 indicated that gradually by the end of 1943, all the motor disruptions had been restored. There remained only a reduction in sensitivity in the zone of innervation of the median nerve. During the examination conducted on 3/29/1946, fine differentiated movements of the II and II fingers turned out to be quite difficult. "The hand freezes", noted the patient. A reduction in sensitivity was noted with an element of hyperpathy in the zone of innervation of the median nerve. The patient was a hydrographer, but was unable to work in his field of specialization due to the incomplete restoration of sensitivity and stable vasomotor disorders.

The stability of sensitivity, vascular and trophic disorders with injury to the median nerve must always be kept in mind during military and work-related examination. The underestimation of the indicated specifics of injury to the median nerve may lead to rather unpleasant consequences. The following observations may serve as an example of this.

1. On 6/4/1943, wound patient N. received an open bullet wound to the right elbow joint. Movement was disrupted in the fingers, burning pains and a loss of sensation was noted. After healing of the wound, which occurred in 3 months, the patient was assigned first to the convalescent battalion, and then to the railway battalion for non-construtution duty. As a result of frostbite, ulcers appeared on the fingers. During an examination conducted on 6/4/1944, i.e., exactly one year after the injury was sustained, it was finally established that there was damage to the median nerve with partial disruption in conductivity and acute trophic disorders. The II and III fingers were cyanotic, there were ulcerations on the terminal phalanx of the III finger and sharp ungual changes on the II finger. During an operation performed on 6/7, the median nerve turned out to be surrounded by a scar and had an intra-trunk neuroma. A resection was performed and a suture applied. After the operation the trophic disorders were gradually evened out, and by the end of the month the trophic ulcer had healed completely.

2. Wounded patient B. received an open bullet wound to the left shoulder on 8/6/1943. "The I, II, and III fingers were numb and would not move". After a month, when the wound had healed, the patient was discharged and was wounded in the leg. Two-and-a-half months later he was discharged and and assigned to the reserve regiment. As a result of frostbite there appeared small ulcers on the II and III fingers, for which he was admitted to the hospital on 6/5/1945. Upon examination, a complete disruption of the motor function was found, with partial retention of deep pain sensation in the zone of innervation of the median nerve (hyperpathy). Acute trophic disorders were present: cyanosis and thinning of the skin on the IV, III and particularly the II finger, sharp growth of the subungual bed, deformation of the nail and an ulcer which would not heal on the end phalanx of the II finger.

On 6/23 during the operation, two intra-trunk neuromas and obliteration of the brachial artery were discovered.

In both patients with mildly expressed motor and sensitivity disorders there were acute vascular and trophic disruptions whose underestimation facilitated to a certain degree their insufficient treatment and early discharge. These examples illustrate once again that wounded patients with injury to the median nerve, even with satisfactory motor function and restoration of sensation, have the right to long-term limitation of work assignment, considering the inclination of the injured extremity toward trophic disorders which arise most easily from burns and frostbite.

The ulnar nerve. According to the frequency of injuries to the nerve trunks of the upper extremities, wounds to the ulnar nerve, according to the materials for the development of illness histories, turned out to be in third place.

The clinical picture of injury to the ulnar nerve varied depending on the degree and localization of the injury. Most of the wounded patients indicated a loss of movement in the fingers (most often in all the fingers, somewhat more rarely only in the V and IV fingers). According to the materials of personal observation, in approximately 13.0% of the cases there was noted a rigidity of the

fingers, particularly the IV and V at the moment of injury. Both of the indicated types of disruptions in movement arose primarily in wounded patients with injuries to the ulnar nerve at the forearm.

Often wounded patients, particularly with injury to the shoulder, said that at the moment the wound was sustained, the arm or hand "was taken away", "dropped", "did not function". In comparing these /129 sensations at the moment the wound was sustained with the character and degree of changes in the nerve trunk found during operation, we were able to confirm that the disappearance of movement, as well as the contraction of the fingers (particularly the V and IV), the loss of movement in the hand, are observed most often in patients with anatomical severance of the ulnar nerve.

The feeling of numbness and pain (particularly of a burning character) arose at the moment of injury more frequently in those patients in whom with revision on the operating table, the ulnar nerve turned out to be macroscopically whole. A usual discovery was scars around the nerve trunk, more rarely cicatrical changes in the nerve trunk or an intra-trunk neuroma were found.

With injury to the ulnar nerve at the forearm, adduction and abduction of the fingers was disrupted, particularly the IV and V fingers. Abduction of the thumb became impossible. As a result of the disruption of innervation in the interosteal and vermicular muscles, the primary phalanges gradually settled into an extended, and the terminal and central phalanges -- into a flexed position. It is usually considered that the indicated position of the fingers in combination with atrophy of the interosteal spaces leads to change in the form of the hand ("claw-shaped hand"). We observed the typical "claw-shaped hand" only with isolated injury to the ulnar nerve in singular cases. More frequently there was a "claw-shaped" position of the V and IV fingers. This evidently depended on the fact that the first and second vermicular muscles were provided by innervation of the median nerve (fig. 52).

Fig. 52. Claw-shaped position of the IV and V fingers with injury to the ulnar nerve at the level of the central third of the forearm.

Sensitivity disorders were noted on the dorsal and palmar half of the hand, the dorsal surface of the V, IV and half of the III finger, and on the skin of the palmar surface of the V and the ulnar half of the IV finger. Anesthesia was observed more frequently in the fifth finger. In the remaining zone of cutaneous innervation of the ulnar nerve there was hypesthesia, often with elements of hyperpathy, even in cases of complete severance of the nerve trunk established during the operation.

According to the materials for the development of illness histories, with firearms injuries to the ulnar nerve, the following relations of sensitivity disorders were noted (table 17).

The articulatory-muscular sensation is usually disrupted in the IV and V fingers, more often only in the V finger.

It is necessary to stress that if the superficial sensitivity was to a certain degree disrupted in all the patients, the articulatory-muscular sensation turned out to be retained, according to the

materials of personal observations, in 12.0%, although in individual cases there was anatomical severance of the trunk.

Table 17 /130

Relation of the frequency of sensitivity disorders with injuries to the ulnar nerve

| Character of sensitivity disruptions | Number in percentages |
|---|---|
| Hypesthesia | 62.6 |
| Anesthesia | 33.4 |
| Disorders were absent | 1.6 |
| Hyperesthesia | 1.5 |
| Causalgia | 0.6 |
| Palpatory soreness of the nerve trunk | 0.2 |
| Paresthesia | 0.1 |

Vibratory sensitivity in all cases of injury to the ulnar nerve was usually reduced along the entire hand, and more intensively in the IV and V fingers. With complete severance of the trunk it could be lost completely in the V finger and sharply reduced in the IV finger (I. Yu. Kokhanovskiy).

With injury to the ulnar nerve at the shoulder, the indicated clinical picture was complicated by the disruption of the function of hand flexion, as well as flexion of the end phalanges of the nameless finger and fifth finger. The "claw-shaped" position of the IV and V finger was usually mildly expressed, and with partial disruption in conductivity it was not noticed at all.

Changes in the tendinous and periostal reflexes with injuries to the ulnar nerve, as a rule, were not observed. In individual cases it was possible to note a reduction in the carpo-radial reflex.

Trophic and vasomotor disruptions, according to the materials for the development of illness histories, were noted with injury to

the ulnar nerve in 42.0%. Patients voiced frequent complaints of coldness in the injured arm, and sometimes cyanosis of the fifth finger was noted. Often there was observed disorders in perspiration in the zone of cutaneous innervation of the ulnar nerve, anhydrosis with full disruption of conductivity, hypo- or hyperhydrosis with partial retention in the conductivity of the nerve trunk.

Of the generally accepted diagnostic tests, the most successful turned out to be the following:

1. With a horizontal position of the hand, adduction and abduction of the fingers is impossible or sharply limited. These functions were often retained for the index finger due to innervation by the median nerve.

2. Upon touching the palmar surface of the hand with the hosizontal plane of the table, the patient cannot perform a scratching motion with his fifth finger (fig. 53).

3. The patient cannot hold an object, for example, a piece of thick paper, between the pulpous part of the thumb, bent at the interphalangeal joint, and the radial surface of the index finger (fig. 54).

4. Making the hand into a fist takes place without the participation of the IV and V finger or with sharp limitation of their flexion.

The presented tests of locomotory disorders in combination with sensitivity disorders made it possible to establish injury to the ulnar nerve without particular difficulties.

Certain difficulties arose in solving the problem of the degree of injury, since often the zone of innervation of the ulnar nerve is covered also by neighboring nerves, most often the median. The underestimation of the possibility of anastomoses was often the basis for erroneous reasoning as to the speed of restoration of conduct- /131 ivity after application of the nerve suture. The role of the com-

pensatory mechanisms in injuries to the nerve trunks was repeatedly illuminated in the literature during the time of the Great Patriotic War. We may indicate, for example, the works of A. I. Geymanovich, M. G. Ignatov, K. G. Terian. In individual cases with a clinical picture of partial preservation of conductivity, the operation revealed a severance of the trunk with divergence of the ends of the injured nerve.

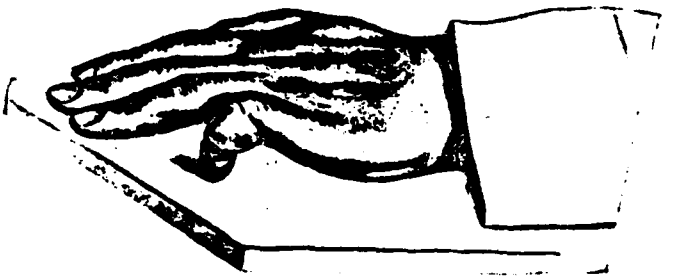

Fig. 53. Test for "scratching" with the fifth finger to show injury to the ulnar nerve.

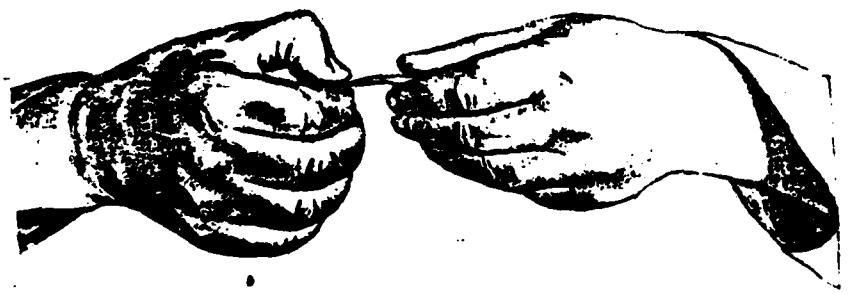

Fig. 54. When extending a piece of paper, the thumb flexes on the side with paralysis of the ulnar nerve (the left side of the illustration); On the side of paralysis of the median nerve, it is impossible to hold onto the paper by flexing the thumb (right side of the illustration).

In the overwhelming majority of wounded patients under our

observation for 2-4 months, the restoration of function after paralysis of the ulnar nerve took place rather gradually and often remained incomplete. This is particularly true of wounds to the forearm. Usually the movement of the hand flexors was restored first, then the fingers, which often led to an intensification of the "claw effect" of the hand. The restoration of movement of the small muscles in the hand took place very late, and then only partially, and most often did not occur at all. Differentiated movements of the /132 fingers were not fully restored as a result of irreversible changes in the small muscles of the hand. If these movements were performed more or less satisfactorily with any injuries to the ulnar nerve, they were provided by the compensatory functions of the other muscles.

Indications of the restoration of functions of the ulnar nerve are:

1. With position of the hand palm downward on a table, the possibility of active adduction and spreading of the fingers in a strictly horizontal direction.

2. The possibility of performing (with the same position of the hand) scratching movements with the fifth finger.

3. The possibility of active palmar flexion of the II-V fingers in the carpo-phalangeal articulations with simultaneous extension of the fingers in the other joints and adduction of the I finger.

The axillary nerve. As we know, with injury to the axillary nerve, atrophy of the deltoid muscle occurs quite rapidly. The earlier the injured extremity is immobilized, the greater the chances of preventing the ligaments in the brachial articulation from stretching and the greater the chance of preventing the possible emergence of subluxation. We considered it expedient to subject all wounded patients with injuries in the area of the axillary space and the brachial articulation to neurological examination.

The basic test for injury to the axillary nerve is the disruption in the function of lifting the arm to a horizontal line. This function often suffers as a result of injury to the brachial articulation itself. A valuable differentiating indicator is the disruption of sensitivity along the posterior-external surface of the upper third of the shoulder.

In wounded patients with injury to the axillary nerve accompanied by fractures of the brachium, the latter did not heal for a particularly long period of time.

The musculo-cutaneous nerve, which comes out of the external trunk of the brachial plexus together with the median nerve, was also rarely subject to isolated injury. According to the materials of personal observations, injuries to the musculo-cutaneous nerve were noted in 0.2% of the cases (O. V. Nazarova and K. P. Chikovani). Usually, combined injuries of the musculo-cutaneous nerve and the upper part of the brachial plexus were noted ($C_5$ and $C_6$). Isolated injuries to the musculo-cutaneous nerve were noted in traumas to the muscle masses of the anterior surface of the shoulder, and with injuries to the brachium.

Characteristic for complete severance of the nerve is the loss of innervation of the coracoid-brachial, biceps, and brachial muscle with disappearance of the elbow flexion reflex. In these cases, anesthesia was observed in the form of a narrow strip in the area of the external surface of the forearm to the line of the radio-carpal articulation. It is caracteristic that flexion of the forearm was partially retained due to the function of the brachio-radial muscle, obtaining innervation from the radial nerve.

Flexion was also retained even with a high level of injury to the musculo-cutaneous nerve, evidently due to the rich nerve connections with the median nerve, whose composition sometimes includes fibers passing to the flexors, most often to the brachial muscle.

Injury to the peripheral section of the nerve gave only a loss of sensitivity along the outside edge of the forearm. The restoration of the musculo-cutaneous nerve took place comparatively well, with reliable contact of the segments of the external trunk of the brachial plexus and the absence of gross intra-trunk fibrose degeneration.

Simultaneous injury to several nerve trunks. According to the statistical data of the First World War, simultaneous injury to several nerve trunks comprised an insignificant percentage. In /133 subsequent ward this percentage rose considerably. According to the materials for the development of illness histories, simultaneous injury to several nerve trunks of the upper extremity were noted in 20.6% in relation to all nerve trunk injuries. Injuries to the ulnar and median nerves comprised 8.2%, to the radial and median -- 5.4%, to the radial, median and ulnar -- 5.0%, and to the ulnar and radial -- 1.9%.

The clinical picture of combined injury to the nerve trunks was compiled from the indicators characteristic for each of them separately. The degree of expression of the symptoms depended on the character and degree of injury to the nerves.

Considerable attention during the Great Patriotic War was given to wounded patients with injuries to the neuro-vascular fascicle at the level of the shoulder. As we know, trauma to the vessel without injury to the nerve trunks may cause serious motor, sensory and trophic disruptions. These disorders are significantly intensified with simultaneous injury to the peripheral nerves. The clinical picture of injury to the neuro-vascular fascicle faries from a light degree of ischemic neuritis to severe ischemic paralyses and contractures. With typical ischemic neuritis, the locomotory and sensitivy disorders develop according to the segmentary type, increasing as they near the periphery. Added to the indicated disorders is the absence of a pulse distally to the area of injury, coldness and swelling of the extremities, lowering of blood pressure, and often burning pains. In the mechanism of the above-mentioned disorders,

aside from direct injury to the nerve trunks, ischemia, a significant role is given to centers of irritation in the periarterial and circumvenous network of the nerve fibers (N. I. Grashchenkov, N. M. Itsenko, V. N. Shamov et al.).

The most severe motor, sensory and trophic disruptions were present in patients who received bandaging of the brachial artery immediately after sustaining the wound. The clinical picture was considerably worsened also in later periods after bandaging of the artery due to its aneurism without preliminary training for the development of collateral blood circulation.

In the overwhelming majority of patients with injuries to the neuro-vascular fascicle, there was no typical clinical picture of ischemic paralysis, although in a number of cases injury to the brachial artery was confirmed during the operation during revision of the neuro-vascular fascicle. The clinical picture basically is composed of indications of the disruption in conductivity to one degree or another of the ulnar and median nerve, often in combination with injury to the internal cutaneous nerve of the forearm and change in the pulse in the radial artery.

In respect to the pulse, it is necessary to note that its presence or absense is not always an indicator of the injury or preservation of the brachial artery. According to Ye. S. Chalyk and according to the materials of personal observations, the retention of the pulse does not speak counter to injury to the vessels. P. M. Saradzhishvili observed an absence of pulse in the radial artery with preservation of the vessels.

In half of the wounded patients, the injury to the neuro-vascular fascicle in the first days after the trauma was accompanied by a loss of movement in the entire arm, with a gradual restoration of the lost function, primarily in the proximal segment of the damaged extremity. All the patients exhibited sensitivity disorders to one degree or another (more often loss of pain and tactile sensitivity /134

in the zone of innervation of the ulnar nerve and its reduction with elements of hyperpathy -- in the zone of the median nerve). The articulatory-muscular sensation was lost in all the fingers of the injured extremity, and of the individual fingers -- most often in the fifth finger.

According to the materials of personal observation, 55 out of the 71 wounded patients experienced pains: in 46 patients they bore a burning character. Severe causalgic syndrome was noted in 16 patients. Thus, burning pains were noted in over half of the wounded patients with injury to the neurovascular fascicle. Among the wounded patients with isolated vascular injury, burning pains were observed rarely, and they were less intense than in the wounded patients whose vascular injuries were combined with injury to the nerve trunks or in whom isolated nerve injury was noted.

Since the overwhelming majority of wounded patients with simultaneous injury to several nerves were under the observation of the author for an average of 2-3 months, it is impossible to speak of the later consequences of this type of injury. Nevertheless, an impression was formed as to the stability of locomotory, sensitivity and trophic disruptions. This particularly concerns wounded patients with injury to the neurovascular fascicle.

In conclusion of this section, it is necessary to touch upon the question of injuries to the cutaneous nerves of the upper extremity. A. G. Molotkov has noted in numerous articles and papers that the cutaneous nerves are the basic conductors of pain sensitivity and bear a trophic function. The experience of the Great Patriotic war has shown that injury to the cutaneous nerves leads to significant locomotory, sensitivity and trophic disruptions. F. M. Lampert often noted locomotory disorders associated with injury to the cutaneous nerves of the upper extremities, which he called paralyses which were "anatomically unsubstantiated". In the emergence of reflex paralyses and contractures of the upper extremities, N. A. Popov ascribed a significant role to injuries of the cutaneous nerves.

However, along with the increased interest in the cutaneous nerves during the time of the Great Patriotic War, it must nevertheless be stressed that the role of the cutaneous nerves was often underestimated in cases of firearms injuries to the extremities.

A number of articles appeared during the time of the Great Patriotic War which presented statistical data on the frequency of wounds to the nerve trunks. However, only scant evidence is available on the frequency of injuries to the cutaneous nerves. During clinical examination and operative intervention, attention was not always focused on the condition of the cutaneous nerves. Based on the material of personal observations, we were able to confirm the frequency of injuries to these nerves, as well as the frequency of the causalgic syndrome in wounded patients having simultaneous injury to the basic nerve trunks and the cutaneous nerves, particularly the internal cutaneous nerve of the shoulder. Burning pains were noted in 10 out of 34 wounded patients suffering simultaneous injury to the ulnar, median and cutaneous nerve of the forearm with the absence of vascular injury. Of 25 wounded patients with a severe form of causalgia, in 13 of them the injury to the median and ulnar nerve was combined with injury to the internal cutaneous nerve of the forearm. In all cases the wound was at the level of the shoulder, where isolated injury to the median nerve was often accompanied by causalgic syndrome. Nevertheless, the role of the cutaneous nerves in the mechanism of emergence and intensity of causalgia should not be dismissed for lack of evidence, particularly since in two of the wounded patients with isolated injury to the internal cutaneous nerves of the shoulder and forearm /135 there was observed a typical causalgic syndrome.

With wounds to the ulnar nerve, burning pains were rarely observed and were weakly expressed. However, in one case the intensity of the burning pains was considerable, and expressed synesthesialgia was present. This observation concerns a patient having simultaneous injury to the ulnar and interior cutaneous nerve of the forearm. The following excerpt from the illness history may serve as an illustration.

Wounded patient P. After a firearms inflicted injury to the left shoulder sustained on 8/18/1944, movement immediately disappeared in the fingers, and two weeks later pains appeared in the hand, taking on a burning character by the end of the third month. After neurolysis with partial resection of the ulnar nerve performed on 11/30, the pains in the internal surface of the forearm intensified. Upon examination performed on 2/25/1945, partial disruption in the conductivity of the ulnar nerve, atrophy of the interosteal muscles, disruption in adduction and abduction of the fingers with the exception of the II finger were found. There was also a weakening in the flexion of the V and IV fingers, as well as their extension in the interphalangeal articulations.

There was noted a loss in pain and tactile sensitivity on the ulnar half of the hand, on the V and half of the IV finger. The articulatory-muscular sensitivity in the fifth finger was lost. The reduction of pain and tactile sensitivity on the internal surface of the forearm indicated that there was also an injury to the internal cutaneous nerve of the forearm. A pinch and even simple touching of the internal surface of the forearm and hand in the zone of ulnar nerve innervation on the side of the injury caused an unpleasant sensation. This sensation, although less acutely expressed, arose upon examination with pinching or touching on both sides in the zones from the third cervical to the fourth thoracic segment, inclusively. Under the effects of conservative therapy, the burning pains gradually subsided and the synesthesialgia was resolved. During the examination performed on 8/28/1945, there were noted residual manifestations of injury to the ulnar nerve in a stage of restoration, weakly expressed pain upon pinching the internal surface of the forearm.

The brachial plexus. According to statistical data from the First World War, wounds to the brachial plexus occupied fourth-fifth place according to the frequency of injury to individual nerve trunks of the upper extremities. According to the materials for the development of illness histories, firearms injury to the brachial plexus occupies sixth place among all injuries to the nerve trunks of the upper extremity and comprises 5.8% of the firearms wounds to the peripheral nervous system.

Most of the wounded patients suffered tangent wounds in the supraclavicular or subclavicular regions, as a result of which primarily partial paralyses of all the trunks in the plexus or of part of them occurred. Injury to the primary trunks was observed more

frequently with injuries to the supraclavicular region, and to the secondary trunks -- with injuries to the subclavicular region. This position was confirmed in the materials published during the Great Patriotic War.

According to the materials of personal observations (132 cases), wounds to the brachial plexus occupied third place by frequency of injuries to the nerve trunks of the upper extremities.

With complete disruption in the conductivity of all the trunks of the brachial plexus, there was observed a flaccid paralysis of the upper extremity (the arm drooped and was limp) with anesthesia along its entire course with the exception of the upper section of the deltoid region innervated by the supraclavicular nerves from the cervical plexus. There was also loss of the articulatory-muscular sensitivity to the radiocarpal, and sometimes even to the ulnar articulation inclusively. Tendinous and periostalic reflexes were not evoked.

In the overwhelming majority of the wounded patients there was partial injury to all the nerve trunks. The clinical picture was quite varied. It depended on the degree of damage to one nerve trunk or the other.

In the first few days after injury, all the wounded patients noted sharply expressed diffuse locomotory and sensitivity disorders with their gradual resolution. By the time of examination (on /136 the average 2-3 months after the wound was sustained), total absence of movement in the arm was noted only in singular cases. The most stable and sharply expressed were usually locomotory disorders in the distal regions of the extremity, particularly the adduction and abduction of the fingers. One-fifth of the wounded patients experienced distinct atrophy of the shoulder girdle. The atrophy of the hand muscles was often masked by its edema. Painful rigidity in the joints was noted primarily in patients experiencing pains of a particularly burning character, as well as in patients with long-

term immobilization of the injured extremity. Among the tendinous and periosteal reflexes, the carpo-radial was in first place by frequency of loss. Disruptions in superficial sensitivity were determined primarily in the zones of cutaneous innervation of the fifth and sixth cervical root. Hyperpathy was often noted in the zone of innervation of the median nerve. Disruptions in articulatory-muscular sensitivity were observed less frequently as compared with disruptions in superficial sensitivity. Loss of the articulatory-muscular sensation in the V and IV fingers was most frequently noted. According to the materials of personal observations, burning pains were noted in 60.0% of all cases, and severe causalgic syndrome -- in 14.0%.

Cyanosis, edema, and particularly trophic changes in the hand (thinning, ungual hyperkeratosis, elongation, ungual brittleness) were noted in approximately one-third of all the cases. They were sharply expressed in wounded patients in the presence of severe causalgic syndrome.

Although most of the wounded patients used a scarf bandage, nevertheless there was frequently noted a clear configuration of the head of the brachium resulting from atrophy of the deltoid muscle and extension of the ligaments and bursa of the brachial articulation.

According to the materials of personal observations, simultaneous injury to the trunks of the brachial plexus and the vessels was noted in 31 wounded patients out of a total of 132. Sixteen patients exhibited aneurism of the subclavicular artery, 6 -- arterio-venous aneurism. Five patients received ligation of the subclavicular vessels in the first days after the wound was sustained. With the exception of cases with acute onset of ischemia after ligation of the subclavicular vessels, the clinical picture differed little from that which was observed with isolated injury to the trunks of the brachial plexus. In patients with aneurism of the subclavicular artery, only in individual cases were cyanosis and edema of the hand noted. More frequently there was observed a weakening of the pulse rather than a loss of it. Unlike patients with isolated injury to the brachial

plexus, in this category of wounded the absence of tendinous and periosteal reflexes was most apparent even in those cases when the locomotory and sensitivity disruptions were expressed to an insignificant degree. This, evidently, must be related to the particular sensitivity to disruption of the blood circulation of the nerve fibers which comprise the reflex paths. Burning pains were noted in 13 patients.

Trophic disorders -- thinning of the skin, smoothing of its wrinkles, hyperkeratosis and changes in the fingernails -- were noted in patients who had not suffered aneurisms, but had indications for vascular ligation, and it was only the absence of the pulse on the radial artery which forced us to believe that the vessels were involved in the pathological process. In these cases, as a rule, manifestations of irritation were prevalent. Anhydrosis was observed only with complete disruption of blood supply to the injured arm.

The presence of a pulsating tumor, as well as a murmur which is often felt by the patient himself and easily discerned during auscultation, was the basic indicator making possible the diagnosis of an /137 aneurism. However, this diagnosis was often not pronounced at the preliminary stages of evacuation.

The affliction of the fifth and sixth root or the upper trunk of the brachial plexus (Erb-Dyushen paralysis) entails a loss in the function of the musculo-cutaneous and subaxillary nerve and a break in the fibers within the composition of the radial nerve running to the brachio-radial muscle, as well as the fibers going within the median nerve to the circular pronator and radial flexor of the hand. Observed under clinical conditions is a limitation in the lifting of the shoulder and flexion of the forearm, with disruption of sensitivity along the external surface of the shoulder and forearm. Reflex from the biceps muscle is absent.

Injury to the eight cervical and first thoracic root or the lower (internal secondary) trunk of the brachial plexus (Klyumpke-

Dezherin paralysis) is manifested by a clinical picture comprised of the disruption in the conductivity of the ulnar nerve, the internal cutaneous nerves of the shoulder and forearm and the fibers running within the median nerve to the digital flexors (paralysis and atrophy of the small muscles of the hand, flexors of the hand and fingers in combination with disruptions in sensitivity in the zones of innervation of the ulnar and internal cutaneous nerve of the forearm).

The clinical types of upper or lower paralysis under wartime conditions are noted primarily with direct wounds to the supra- and subclavicular regions, usually accompanied by severe injuries to the subclavicular vessels and the lung tissue, often leading to death. Therefore, wounded patients with the indicated forms of injuries to the brachial plexus rarely get to rear hospitals. Moreover, with a background of severe general condition of the wounded patients, attention is not always focused on the nerve trunks of the brachial plexus.

1. Wounded patient T. sustained a fragment wound in the underarm region on 3/12/1942. In the first day after the wound was sustained there was no movement in the arm. Only on the following day did flexion appear in the IV and V fingers.

Upon examination performed on 10/25, there was noted an atrophy of the shoulder and the forearm, limited movement in the brachial articulation (weakness in the deltoid muscle), absence of extension in the forearm, hand and fingers with other movements of the hand and fingers being well retained. With impact of a mallet on the triceps muscle tendon, flexion was noted in the ulnar articulation. The ulnar flexion and carpo-radial reflexes were weakened. A reduction in sensitivity on the dorsal-exterior surface of the shoulder, the forearm and the back of the hand in the area of the I-III fingers was noted.

2. Deserving of particular attention is wounded patient A., in whom, resulting from bilateral injury to the subclavicular regions there was on the right side an injury to the brachial plexus with predominant injury to the internal and dorsal, and on the left -- the external and dorsal trunk. Upon examination performed 17 months after the wound was sustained, the right arm exhibited limited movement in the brachial articulation to a horizontal line (the scar was in the way), there was good flexion of the forearm with absence

of its extension, and there was slight flexion in the hand and fingers. Other movements in the hand and fingers were absent. There was a limitation in the passive movements in the brachial, radiocarpal articulations and the fingers, and atrophy of the hand muscles. The carporadial reflex and the reflex from the triceps muscle could not be evoked.

The reduction of sensitivity was noted on the internal surface of the shoulder, the forearm, and the ulnar half of the hand. Articulatory-muscular sensitivity was lost in the IV and V fingers. There was also no perspiration on these two fingers. The pulse on the radial artery was weakened.

In the left arm there was a hint at movement in the brachial articulation, satisfactory flexion of the forearm primarily due to the brachio-radial muscle, but absence of its extension. There was good flexion in the hand with loss of its extension, digital flexion was within the limits of rigidity, with good digital adduction and abduction. There was atrophy of the shoulder girdle. Reflexes could not be evoked. The pulse was good, and perspiration was noted on the entire hand. There was a reduction in sensitivity with elements of hyperpathy on the external surface of the shoulder, forearm, and radial half of the hand. The articulatory-muscular sensitivity was completely lost in the I and II fingers.

The materials of personal observations did not allow us to observe the dynamics of the clinical picture of firearms injuries to the brachial plexus in most of the patients. Nevertheless, based /138 on a number of cases and on the comparison of data noted in the illness histories at stages of evacuation, we may be assured of the presence of undoubted improvement in the condition of the overwhelming majority of patients, particularly in the improvement of the motor function. Usually the restoration of movement began with the proximal sections, with the exception of those patients in whom injury to the external trunk was prevalent. The disruption in the function of the hand muscles was retained the longest.

In individual cases of slight injuries to the brachial plexus, rapid restoration of conductivity was observed.

The following observation may serve as an example of this.

Wounded patient O. sustained an open bullet wound to the left half of the chest with injury to the lung on 2/16/1941. Upon examination performed 7/29, the left arm hung limp, and there were no active movements in it. Reflexes could not be evoked, and hyperesthesia was noted along the entire left arm. On 8/6 there was observed only an insignificant limitation of movement in the brachial and ulnar articulations with good movements in the hand and fingers.

The most severe course of injuries to the brachial plexus occurred in patients who had been subjected to bandaging of the vessels immediately after wounding. However, even in these cases it was sometimes possible to achieve good results by the application of energetic conservative therapy.

Wounded patient K. sustained an open bullet wound to the left subclavicular region, accompanied by abundant bleeding with loss of consciousness and edema of the hand, on 10/28/1945. Two hours later the subclavicular artery was ligated, after which there was a complete disappearance of movement in the arm and edema was intensified, "the I and II fingers became hooked and they turned blue". At the same time, burning pains appeared ("it burned along the entire arm"), and sensation was lost in the arm. Energetic physiotherapeutic and hospital resort treatment was performed.

After 2-3 months, movement was gradually restored in the brachial and ulnar articulations and sensation was regained in the proximal regions of the arm. During an examination performed on 5/24/1946, atrophy of the shoulder, forearm and small muscles of the hand was found. The muscles in the forearm were hard to the touch, active and passive movements in the shoulder and elbow joints were in full volume and sufficient force. Pronation, supination and extension of the hand were limited due to rigidity. Flexion of the hand was absent, slight flexion in the end phalanges of all the fingers was noted, and adduction and abduction of these phalanges were absent (rigidity of the fingers, the I finger is adducted to the others).

Reflexes from the biceps muscle and the carpo-radial reflex were not evoked. When the elbow extension reflex was evoked, a weak contraction was noted in the triceps muscle, a significant contraction in the thoracic muscle, and slight extension of the hand. The hand was pale and dry, with thinning and smoothness of the skin folds. Increased perspiration was noted in the armpit. There was no pulse in the radial artery.

There was a reduction in the pain and tactile sensitivity on the back of the hand in the zone of innervation of the radial nerve, hyperpathy on the palmar surface of the I finger and in the region of its intumescence. There was anesthesia in the other areas of the hand. Soreness was noted along the course of the median nerve with irradiation of pain into the I, II, and III fingers, along the course of the ulnar nerve with irradiation into the IV and V fingers. Pain upon palpation of the course of the radial nerve was also projected there.

During the examination performed on 8/30, an increase was found in the force of movements in the brachial and ulnar articulations. Flexion of the hand appeared within a limited margin as a result of rigidity, as well as good extension of the primary phalanges. With a relatively good flexion of the end and central phalanges, the patient was unable to perform the isolated flexion of the fingers. Adduction and abduction of the fingers was absent, and atrophy of the hand muscles became apparent. A reduction was noted in the sensitivity at the forearm, and there was anesthesia on the ulnar half of the hand with a shade of hyperpathy. The articulatory-muscular sensitivity was lost in the fingers. Perspiration appeared on the back of the thumb and in the area of its intumescence, and soreness along the course of the nerve trunks was retained.

According to the materials of personal observations, out of 17 patients subjected to operation on the vessels of the subclavicular region, only three exhibited a growth in motor and sensitivity disruptions in the first days after removal of the aneurism. The others /139 experienced no changes or it was impossible to note a significant improvement. All these wounded patients were subjected to operation, after which they were given thorough and prolonged training for development of the collaterals, which significantly improved the outcome of the operative intervention on the vessels. The following observations may serve as an illustration.

1. Immediately after an open bullet wound sustained to the left subclavicular region on 8/18/1943, patient K. experienced "limpness" of the left arm, and burning pains appeared on the palmar surface of the hand. Ten months later there was noted a limitation in movement in the shoulder and elbow joints, good extension of the hand and the primary phalanges, limited extension of the terminal phalanges of the II and III fingers, and inability to extend the IV and V fingers. Closure of the fingers into a fist was limited, and their adduction and abduction were absent. A loss of sensitivity was found on the internal surface of the forearm, the ulnar half of the hand, on the IV and V fingers with hyperpathy in the zone of innerva-

tion of the median nerve. Articulatory-muscular sensation was completely lost in the IV and V fingers, in the end and central interphalangeal articulations of the II and III fingers. Reflexes could not be evoked from the triceps muscle and the carpo-radial.

One year after the wound was sustained, removal of the arterio-venous aneurism of the subclavicular vessels was performed. One month after the operation, there were essentially no changes in the condition of the nervous system as compared with that recorded after the wound was sustained, with the exception of restoration of articulatory-muscular sensation in the II and III fingers.

2.After a wound to the chest sustained on 3/28/1944, the right arm of patient immediately went limp, and a day later there was a racking pain in the arm. After 1½ months there was noted an acute atrophy of the shoulder and forearm, insignificant flexion of the terminal phalanges; reflexes could not be evoked. Sensitivity turned out to be reduced, more on the external surface of the shoulder and forearm, with hyperpathy in the zone of innervation of the median nerve. Articulatory-muscular sensation was retained. There was established maceration of the skin on the palm, cyanosis of the hand, and weak pulse. Ligation of the subclavicular vessels was performed 3½ months later, and removal of the aneurism of the subclavicular artery and neurolysis of the plexus trunks was performed two weeks after then.

During the examination performed one month after the operation, satisfactory movement was found in the brachial and ulnar articulations, a hint at extension of the hand, adduction and abduction of the fingers, and slight flexion of the III, IV and V fingers. There was a reduction in sensitivity on the hand, with the retention of articulatory-muscular sensation. The pulse was absent in the radial artery. There was acute soreness of the nerve trunks. Reflexes could not be evoked. There was cyanosis of the hand and smoothing of the skin folds.

Thus, one month after removal of the aneurism and neurolysis of the plexus, considerable improvement was noted, particularly in the locomotory function.

Experience has shown that with differential diagnosis of injuries to the brachial plexus, particularly to its roots, consideration must also be given to symptoms stemming from the spinal cord. However, it must be noted that even with anatomical integrity of the latter, symptoms of organic injury to the spinal cord have been observed which are based on accompanying concussions, contusions, or hemorrhaging.

With transverse open wounds to the nect, immediate quadriplegia was sometimes observed, accompanied by severe pains of a radicular character, primarily in the upper extremities and often in the presence of disrupticns of the pelvic organs (B. S. Doynikov). The symptoms of bilateral damage to the spinal cord which occurred in these cases yielded to the Brown-Sekar symptom complex after a certain time. It should also be indicated that it is particularly this form which was accompanied by the Gorner symptom complex (dilation of the pupils, the lid slit, and retraction of the eyeball).

In connection with the varied character and level of injury to the brachial plexus and with combined injury, its course and prognosis for wounds to the brachial plexus were quite varied. Hemorrhaging in the region of the brachial plexus and in its trunks without disruption of the integrity of the elements in the plexus itself /140 followed the lightest course. In the presence of ruptures of major vessels and formation of hematomas with subsequent formation of aneurisms, there was a gradual compression of the brachial plexus. Even when the trunks of the plexus were intact, pareses in the presence of large aneurisms sometimes became total paralyses, which hindered the diagnosis and the estimation of the possibility of restoring the function of the brachial plexus.

A. Yu. Sozon-Yaroshevich indicates the widespread distribution of cicatrical processes of the plastic type observed after firearms injuries to the brachial plexus. He associates the development of these scars with the formation of connective tissue around the nerve trunks at the place where the hematomas had been, which were often afflicted by infection. Sometimes fusions of vessels, nerves and bone formations into a common conglomerate were noted. Such fusions hindered the regenerative process in the nerve trunks.

Of all the types of firearms injuries to the brachial plexus, the most prognostically unfavorable turned out to be tears in the brachial plexus at the point of emanation of the roots from the spinal cord channel. Here, large diastases were always formed, as a result of which hope was completely lost for spontaneous regeneration.

Cases of injury to the brachial plexus directly under the clavicle also had a comparatively severe course. In these cases, secondary trunks of the plexus were damaged and osteomyelitis of the clavicle often occurred. The indicated circumstances hindered and postponed reconstructive operative intervention as well as the regeneration of the trunks of the brachial plexus. A complicating moment was often accompanying suppuration with the subsequent formation of dense scars.

Firearms wounds to the brachial plexus, particularly fragment wounds complicated by osteomyelitis of the clavicle, were sometimes accompanied by severe hemorrhaging from the veing. The liquidation of this hemorrhaging presented great difficulties due to the numerous injuries present in the walls of the veins, often spread over a large expanse.

We must also indicate certain processes complicating the restoration of the function of the brachial plexus -- periarthritis of the brachial articulation, dislocations and subluxations of the head of the femor, etc.

Even with favorable conditions, the regenerative process with injuries to the brachial plexus lasts for years. The muscles of the shoulder girdle and the shoulder are relatively well restored. Complete restoration of the function of the peripheral sections sometimes occurs after several years. More often, however, restoration of the function of the small muscles of the hand may be only partial or may not occur at all.

## The clinical treatment and diagnostics of injuries to the nerve trunks of the lower extremities

According to the materials for the development of illness histories, firearms wounds to the nerve trunks of the lower extremities were noted in 38.3% of the cases in relation to all nerve trunk injuries.

Injuries to the sciatic nerve were sometimes combined with wounds to the upper and lower gluteal artery, and in rare cases -- with injury to the common pudendal artery. Therefore, in cases accompanied by severe hemorrhaging, operative intervention was usually performed already at the preliminary stages of evacuation for the purpose of stopping the bleeding from the above-mentioned vessels.

For operative access to the vessels in these cases, dissection /141 of the margins of large unfolded wounds of the buttocks region was performed. The fear of gas gangrene made it necessary to made large additional incisions through the massive musculature of the buttocks. All this, aside from direct trauma to the sciatic nerve, created a large number of thick scars surrounding the nerve trunk, which presented an additional pathological factor in cases of a high level of injury to the sciatic nerve.

Aside from injury to the sciatic nerve with wounds to the buttocks region, it was necessary to consider the possibility of trauma to the upper and lower gluteal nerve with subsequent atrophy of the gluteal musculature.

With wounds to the lower gluteal nerve, the posterior cutaneous nerve of the hip was often damaged due to the proximity of these formations. Injury to the latter was noted most frequently with traumas to the posterior surface of the hip, under the gluteal fold. These wounds caused anesthesia of the skin at the lower surface of the buttocks region and in the posterior side of the hip.

According to the materials of personal observation (out of a total number of 1,500 observations), wounds to the nerve trunks of the lower extremities were noted in 582 persons. Of these, injury to the sciatic nerve was present in 562 cases. Wounds to the remaining nerve trunks of the lower extremities comprised an insignificant percentage.

The sciatic nerve. According to the materials for the development of illness histories, wounds to the sciatic nerve occupied second place by frequency of injuries, comprising 14.9% of the total number of nerve

trunk injuries.

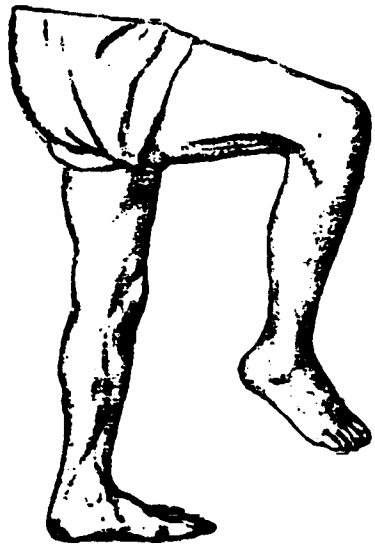

Fig. 55. Hanging of the foot with complete disruption in the conductivity of the fibular nerve.

According to the character of injury and clinical course, all injuries to the sciatic nerve may be divided into two groups: those with the presence of complete and partial disruption in the conductivity of the sciatic nerve.

Injury to the sciatic nerve with complete disruption in conductivity. The basis for a diagnosis of complete disruption of conductivity was the stable absence of movement in the foot and toes, the early emergence of atrophy of the muscles, the loss of the achilles and plantar reflex, loss of pain and tactile sensitivity in the zones of innervation of the sciatic nerve, and the absence of articulatory-muscular and vibratory sensation in the toes.

A study of sensitivity in patients subjected to neurorrhaphy of the sciatic nerve found that: the zone of anesthesia of pain and tactile sensitivity, as a rule, started with the lower third of the external surface of the shin, often from the central third, and very rarely from its upper third, which was due, evidently, to the "covering"

by the external cutaneous nerve of the hip. As a result of the expanded zone of innervation by the posterior cutaneous nerve of the hip, in certain patients anesthesia on the posterior surface of the shin was determined only from its lower third, and even from the heel.

Soreness of the nerve trunk distally to the area of its /142 injury was considered a reliable indication of its partial severance. However, sufficient observations have been accumulated which indicate that this position is not always correct (A. G. Molotkov, V. L. Lesnitskaya). There have been numerous occasions to confirm painful percussion or palpation of the sciatic nerve and its branches distally to the point of its anatomic severance. Sometimes after resection with application of a nerve suture, sensitivity appeared in areas of anesthesia at the external and posterior surface of the shin, primarily with elements of hyperpathy. Thus, the resection of the central end of the damaged sciatic nerve seemed to facilitate the "functional manifestation" of the nerve fibers penetrating into the peripheral end from the neighboring nerve trunks.

Fig. 56. Bilateral injury to the sciatic nerves; on the right is primarily damage to the fibular, on the left -- to the tibial nerve.

When patients were asked what they felt at the moment they were wounded, most often the reply was: "the leg was torn off". Often the wound was accompanied by a feeling of "numbness", lifelessness of the foot with loss of movement in it, sometimes there was the feeling that "the foot was wounded". Half of the patients with locomotory and sensitivity disorders characteristic for a clinical picture of complete disruption in conductivity noted complaints of pains (of a racking character). In one-third of the patients the pains bore a burning character. Six patients resorted to soaking the foot in cold water. In 26 of the patients complaining of burning pains, anatomical severance of the nerve was discovered during the operation. Two of the patients from this group also used foot soaks of the injured extremity. Thus, the presence of pains, even of a causalgic character, does not exclude the possibility of anatomical severance of the nerve trunk.

Initial indications of regeneration were symptoms of irritation on the part of the sensory sphere in the form of pains and paresthesia in the calves and the foot. However, complete restoration in sensi- /143
tivity came considerably later as compared with the locomotory function. The motor function was restored gradually, starting with the proximal sections of the extremity. The last to function was the long digital flexor and the small muscles of the foot (the latter was often not restored at all after neurorraphy of the sciatic nerve).

In evaluating the locomotory function, it is important to focus particular attention on the methodology of study. "The study of initial, rather weak and quickly exhausted active movements must be done in the most comfortable position for discovering the mechanical effect of muscle contraction". (B. S. Doynikov). In actually, often the test for dorsal flexion of the foot in a patient with a drooping foot yielded negative results. However, in bed it was possible to obtain clear contractions of the extensors of the foot and toes.

The most successful test for judging the degree of restoration of the locomotory conductors is the performance of alternating extension, flexion, abduction and adduction by the foot.

We must stress that as a result of the onset of regeneration, with good motor function and restored sensitivity (primarily protopathic), the injured extremity may be substandard in a functional sense for some time. Patients experienced great pains when placing weight on the sole and toes. Also, increased sensitivity to cooling was noted. The indicated signs of unfinished neurotization must be considered in evaluating work capability. The following observation may serve as an example.

> Wounded patient B. was directed after "recovery" to an active duty ship. Strong pains during walking forced him to go to a neuropathologist for consultation.
>
> In connection with his injury, an operation for the application of a suture to the sciatic nerve at the boundary of the upper and central third of the hip was performed. The pains in the foot which intensified after the operation remained for 20-25 days. After 9 months, plantar flexion, and after 1½ years, dorsal flexion of the foot appeared. A "hint" at movement in the toes was found 2½ years after the operation.
>
> Three years after the operation it was established that the patient could not step on the sole of the foot. When he tried to do so, he experienced the sensation of "stepping on needles". Walking barefoot was impossible. This sensation of pain appeared in the last 6 months. A limitation in the active movements of the ankle joint was noted due to rigidity. The function of turning the foot to the side was especially acutely disrupted. There was a "hint" at plantar flexion of the toes. The achilles and plantar reflexes were not evoked, and atrophy of the shin was noted. Tactile sensitivity was reduced on the external surface of the shin, starting from its upper third, and was more acute on the foot. Pin pricks in these zones caused an unpleasant sensation without precise localization of the prick. Pinching was acutely painful on the shin and the sole. There was a slight reduction in the articulatory-muscular sensation in the toes, soreness along the course of the fibular and tibial nerve was particularly sharply noted with pressure on the sole. The sole of the foot was cold to the touch.

The case presented is an example of positive outcome of operative intervention on a nerve, but error was allowed in respect to the evaluation of work capacity of the injured leg. As we know, the fibers which conduct the pain (protopathic) sensitivity are the first to regenerate. This is the source of the unpleasant sensations experienced for a considerable period by the patient, particularly during walking (fig. 55, 56, and 57).

Injury to the sciatic nerve with partial disruption in conductivity. The clinical picture of partial injury to the sciatic nerve is comprised of locomotory and sensitivity disruptions characteristic /144 for the injury to the fibular or tibial segment and expressed in varying degree depending on the character and degree of the injury (fig. 56).

At the moment of sustaining the wound, with a background of numbness the patient often notes burning pains and a sensation of passage of electrical current. Burning pains were noted in the overwhelming majority of this group of patients, and sharply expressed causalgic syndrome, according to the materials of personal observations -- in 30.0% of all cases. Sensitivity disruptions of a hyperpathic character were often observed on the soles of the feet, which hindered many patients from placing their weight on the sole of the foot. It is necessary to note the relatively insignificant percentage of disruption of articulatory-muscular sensation in the examined category of wounded patients with the presence of changes in superficial sensitivity in most of them. Deserving of attention was the retention of articulatory-muscular sensation in the majority of patients in whom partial injury to the sciatic nerve was accompanied by severe causalgic syndrome with manifestations of hygromania and synesthesialgia. The latter category of patients also had severe motor disorders which were quickly restored after elimination of the pain, if stable rigidity had not developed by this time.

Wounded patients with acute pains took a rather typical pose:

with burning pains they preferred to sit currounded by wet cloths, often holding their foot with their hand. When moving on crutches, they tried to hold their leg bent at a straight angle in the hip and knee joint, with the foot hanging down (fig. 55). Contracture in the knee joint was most often observed in the patients of this group. Evidently, in this same category of wounded patients, A. I. Geymanovich observed the foot in the Vernike-mann position with injuries to the sciatic nerve with manifestations of its irritation. The achilles and plantar reflexes were not evoked in the overwhelming majority. With the presence of hyperpathy, a study of the plantar reflex often caused a sharp unpleasant sensation. In many wounded patients, a violent reaction to the study of the indicated reflex was noted.

Presented below is a brief illness history of one wounded patient with bilateral injury to the sciatic nerves and causalgic syndrome, upon the removal of which the locomotory function was rather quickly restored.

> Wounded patient P. As a result of simultaneous wounds to both thighs sustained on 6/28/1944, there was bilateral injury to the sciatic nerves. Immediately both feet "drooped", and burning pains appeared in them, especially in the right thigh, which the patient continuously tried to press with the hands. Upon his arrival at the hospital, he refused to be examined (he could not tolerate touching dry objects and moistening did not help). After several sessions of anodization, the pains subsided somewhat, and it became possible to study the patient. The following was established.
>
> The right leg: good plantar flexion of the foot and toes with a somewhat limited dorsal flexion of the foot. The achilles reflex had been lost. Upon testing the plantar reflex, sharp motor reaction occurred. The articulatory-muscular sensitivity, as well as superficial sensitivity, had not been disrupted. Soreness was noted in the calf muscles and points along the course of the internal plantar nerve.
>
> The left leg: movement of the foot was completely satisfactory, superficial and deep sensitivity was retained, the achilles reflex was lost, and there was acute hyper-esthesia upon testing the plantar reflex.
>
> The patient could not place his weight on the soles of his feet due to sharp pains; he did not use crutches (he

was afraid of falling), and preferred to crawl on all fours. For a month the pains gradually subsided, and in September he began to walk on crutches, and soon afterward without them.

According to the materials for the development of illness histories, with firearms injuries to the sciatic nerve, trophis changes in the muscles were noted in 35.6%, in the skin -- in 7.3%, in the sub- /145 cutaneous fatty tissue -- in 2.9%, in the hair -- in 0.1%, disruption of perspiration -- in 0.3%, in the nails -- in 0.1%, in the bones -- in 0.2%, trophic ulcers -- in 0.5%, combined trophic disorders -- in 51.4%, and trophic disruptions were absent in 1.6% of the cases.

According to the materials of personal observations, among the constant indicators of partial injury to the sciatic nerve are trophic disorders which were often observed in acute form. Cyanosis was noted, less frequently paleness of the foot, inclination toward edema, peeling skin, excessive nail growth, hyperkeratosis, disruptions in perspiration, most often in the form of hyperhydrosis. Trophic ulcers were found in 5.0% of all cases. Unlike wounds with complete disruption of conductivity of the sciatic nerve, these arose in the nearest days after the injury was sustained.

Wounded patient Sh. sustained a wound to the right sciatic nerve at the level of the hip joint on 1/18/1943.

In July 1945 he noted the appearance of movement in the foot and toes. At the same time, two symmetrically located abscesses appeared on both shins, which after a certain time became ulcerated. Soon afterward, two other ulcerations appeared on the right shin.

During the examination performed on 3/6/1946, there was a "hint" at flexion of the toes: the achilles reflex was lost. Upon examination of the plantar reflex, acute hyperesthesia was noted. Anesthesia was present on the external surface of the shin and the back of the foot (pain to pinching); there was hyperpathy of the sole of the foot. The articulatory-muscular sensation was disrupted in the toes. The muscles were hard to the touch, and the pulse could not be felt in the arteries of the foot. Cyanosis of the shin and foot were noted, as well as peeling of the skin. On the external surface of the shin in its central third there was an ulceration with sharply undermined margins and purulent sections. A second ulceration was present at the boundary between the lower and central third of the same shin. A third ulceration was present in the lower third at the boundary between the internal and posterior surface (with purulent sections and unpleasant odor).

All three ulcerations were located on the boundary of zones of innervation of the external and internal cutaneous nerves and the zone of innervation of the internal cutaneous nerve of the thigh.

The fibular and tibial nerve. Firearms injuries to branches of the sciatic nerve were observed much more frequently than injuries to the trunk itself. According to the materials for the development of illness histories, injuries to the fibular nerve were noted in 9.4%, to the tibial nerve -- in 2.0%, and combined injuries of the leg nerves -- in 9.8% in relation to all wounds to the nerve trunks.

Isolated injury to the fibular nerve, as we know, is characterized by the absence of dorsal flexion of the foot (hanging foot), turning it to the outside, as well as the absence of dorsal flexion of the toes with disruptions in the superficial sensitivity along the external surface of the shin and at the back of the foot. The degree of expression of the indicated disruptions, according to the materials of personal observations, depended on the character and level of injuries to the fibular nerve.

The achilles and plantar reflexes, as a rule, were unchanged, and articulatory-muscular sensation was also retained.

Immediately after the wound was sustained, the foot drooped, and its outside edge was pointed downward. The drooping was expressed more sharply than in cases of complete paralysis of the sciatic nerve. The toes are usually somewhat bent at the primary phalanges. The gait was disrupted: due to the hanging and drooping foot in the equino-varus position, the patient first touched the floor with the outside edge of the foot and the toe, and then heavily stepped down onto the floor with its entire surface.

In patients who did not use a splint, extension of the tendons was noted with a slight swelling on the back of the foot. The disappearance of tendon relief in the toe extenders (atrophy) was frequently observed with complete disruption in the conductivity of the fibular nerve.

Often there was isolated damage to the basic branches of the /146 fibular nerve (superficial and deep).

With injury to a deep branch, the foot drooped, but was somewhat abducted and the outside edge was not descended. Disruptions in sensitivity were limited to the sphere of the first dorsal interosteal space. With injuries to the superficial branch of the fibular nerve, a limitation in the movement of the foot outward was noted in combination with disruptions in sensitivity along the back of the foot.

In 14 patients, injury to the fibular nerve was accompanied by pains, often with a burning character on the external surface of the shin and the back of the foot. In one patient, the burning pains intensified in these zones after resection of the fibular nerve. In certain cases butning pains arose or intensified in the zone of innervation of the fibular nerve (particularly the back of the foot) after resection of the tibial nerve. Sometimes with anesthesia of pain and tactile sensitivity in the zone of innervation of the fibular nerve, pain from pinching was observed, particularly on the outside surface of the shin.

Upon restoration of the lost function in patients with injuries to the fibular nerve, dorsal flexion of the foot and its turning outward were the first to appear, and only after a considerable time was dorsal flexion of the toes restored.

The tibial nerve. Firearms wounds to the tibial nerve were noted more often in the area of the popliteal fossa and in the area of the internal malleolus than on the shin. Injury in the region of the popliteal fossa was sometimes combined with wounds to the popliteal vessels, particularly with deep wounds penetrating into the cavity of the popliteal articulation. According to the materials for the development of illness histories, combined injuries to the tibial nerve and the blood vessels comprised 9.9% as compared with other combined injuries to the vessels and nerves.

Wounds to the tibial nerve in the area of the shin were rarely noted, since here the nerve trunk is covered by a thick muscle section of the musculus gastrocnemius and the musculus soleus. Usually it was possible to establish disruption of plantar flexion of the foot, toes, turning of the foot inward (expressed to one degree or another), the absence of the achilles and plantar reflexes. The position of the foot with its dorsal flexion, extended primary phalanges and flexed end and central phalanges (heel foot) was observed quite often with injury to the tibial nerve. The loss of superficial sensitivity on the posterior surface of the shin, on the sole of the foot and the outside surface of the foot was often accompanied by hyperpathy, which greatly hindered walking due to pain in stepping on the sole of the foot. The articulatory-muscular sensation, as a rule, was not disrupted. Only in singular cases was there loss of this type of sensitivity in the IV and V toes. Trophic disruptions were often observed (dryness or, on the contrary, acute hyperhydrosis and peeling skin; in 4 patients acutely expressed hyperkeratosis was observed on the sole of the foot, and in one case there was a trophic ulcer).

Pains, particularly of a burning character, were a constant indication of injury to the tibial nerve. In these cases, the course of the illness sometimes took on a unique character, and causalgic type pains came to the forefront, along with a number of vegetative disruptions. In individual cases, trophic ulcers appeared in the anesthetized areas. With injuries to the nerve in the lower third of the shin distally to the divergence of branches to the musculus gastrocnemius and the long digital flexor, only the small muscles /147 of the foot were paralysed, which usually led to insignificant motor disruptions. However, these disruptions in combination with trophic and sensitivity disorders with elements of hyperpathy considerably limited work capability. A superficial neurological examination of patients with injuries to the distal areas of the shin leads to an incorrect diagnosis.

According to the materials of personal observations, a small group of patients with injuries to the tibial nerve exhibited a satisfactory

function of the foot with an active achilles reflex and only slight limitation in the flexion of the toes. On the sole of the foot there was a reduction in sensitivity, more rarely anesthesia with elements of hyperpathy. The primary complaint of the patients was pain during walking.

Fig. 57. The position of the foot with primary injury to the tibial nerve.

If the indicated changes are underestimated, the impression may be formed that there was insufficient objective data for the complaints. Two patients, whose accuracy of diagnosis evoked doubts, were subjected to operative intervention. In one case, neuroma of the tibial nerve was found in the region of the internal condyle, and in the other the nerve turned out to be cicatrically altered.

An orienting test characteristic for injury to the tibial or fibular nerve is the following: if the patient in a sitting position is forced to lean with his injured leg alternately on the toes and on the heel, then with paralysis of the fibular nerve the patient cannot lean on the heel, and with injury to the tibial nerve it becomes impossible to lean on the toes.

According to the materials for the development of illness histories, simultaneous firearms wounds to the fibular and tibial nerve were noted in 9.8% of the wounds to the lower extremity nerve trunks. The clinical

picture of their injury is comprised of a combination of indicators characteristic for injury to the fibular and tibial nerves separately. As a rule, articulatory-muscular sensation in the toes is disrupted.

In judging the degree of disruption in the conductivity of the fibular and tibial nerve, significant difficulties were sometimes encountered. It was often noted that with exclusion of the functions/148 of the fibular nerve, the function of the tibial nerve would also be disrupted to one degree or another in the initial period after the wound was sustained. In some patients these accompanying disruptions could last for considerable periods. Thus, according to the materials of personal observations, complete absence of movement in the foot and toes was noted in two patients with active achilles reflex and retention of the articulatory-muscular sensation. Upon examination of plantar sensitivity, mixed results were obtained. In one case it was possible to obtain plantar flexion of the foot quite rapidly. The operation which was subsequently performed on this patient established the complete severance of the fibular nerve.

In conclusion to the chapter devoted to injuries of the sciatic nerve, it is necessary to touch upon the question of injury to the sural nerve, which, as we know, is formed from the cutaneous branches of the fibular and tibial nerves and provides innervation to the external surface of the foot and the outside edge of the little toe. We may pause on several observations, when burning pains were present with primary localization on the outside surface of the foot.

1. Wounded patient Z. sustained multiple fragment wounds to the thigh, shin and foot on 8/12/1943. All the fragments were removed with the exception of the one in the foot. Immediately after the wound was sustained, burning pains appeared in the foot, which were eased only by cool baths and moist cold compresses. A compression bandage was also helpful. Anode galvanization somewhat reduced the intensity of the pain. The patient would not allow the outside edge of his foot to be touched. During an examination performed on 9/20, it was established that: the foot was edemic, movement in the foot and toes was fully satisfactory, the achilles reflex was active; there

was a reduction in sensitivity on the sole of the foot, and particularly on the toes; pressure on the muscles of the thigh and shin on both sides was painful (synesthesialgia)

During the operation performed on 10/8, the sural nerve turned out to be cicatrized. There was a foreign body to the front of the outside edge of the achilles tendon adjoining the tibial nerve. It was removed, and neurolysis of the sural nerve was also performed. Immediately after the operation the pains subsided, the patient began to walk, still avoiding placing all his weight on the sole of the foot. A reduction in sensitivity was noted on the external surface of the foot. Here, pinching was painful and there was acute hyperpathy. The articulatory-muscular sensation in the little toe turned out to be weakened.

2. Wounded patient S. sustained a blind fragment wound in the area of the right buttocks, shin and foot. Paralysis of the foot set in immediately. Some time later, the patient began to complain of burning pains in the sole of the foot while retaining good function of the foot and toes. Anesthesia was noted along the outside edge of the foot, with shades of hyperpathy on the heel. When the scar was pressed at the level of the achilles tendon, a burning pain appeared on the outside, with irradiation along the outside edge of the foot. The same pains with the same localization occurred also when the scar was depressed in the area of the buttocks, as well as along the course of the fibular and tibial nerve on the shin. Articulatory-muscular sensation was disrupted in the V and IV digits. After resection of the sural nerve the pain disappeared. Hyperpathy remained on the sole of the foot with the absence of the achilles reflex.

In a patient with severe causalgic syndrome, the sural nerve turned out to be cicatrized. Its neurolysis in combination with removal of the foreign body found near the tibial nerve, eliminated the pains, which were evidently primarily caused by the irritation of the sural and partially the tibial nerve.

In the second case there was multiple injury, evidently with partial damage to the sciatic nerve at various levels (paralysis of the foot in the past, soreness along the course of the sciatic nerve, particularly in the region of the scars). The pains arose spontaneously, as well as with pressure on the sciatic nerve along its entire course, with primary localization of the pains in the outside edge of the foot. They subsided after resection of the sural nerve.

The following case is deserving of particular attention.

Wounded patient S. sustained an open fragment wound to the lower third of the shin with splintering of the fibula on 6/29/1943. The fragment and pieces of necrotized tissue

were removed immediately. During the examination performed on 8/30, a reduction in sensitivity was found on the back of the foot, on the plantar and dorsal surface of the V, IV and III digits with loss of articulatory-muscular sensation in the IV and V digits. There was an ulceration on the heel, and edema of the foot was noted. After a sequestrotomy (11/28), the ulceration surface did not heal for a long time in the center of the operation wound. Edema of the /149
foot was also retained. All this passed only after excision of the fistulous passage and removal of the foreign body (a piece of clothing). Walking was greatly hindered due to pains in the sole of the foot, and acute soreness of the wound scar was experienced with irradiation of the pain into the foot. The revision of 9/16 showed a neuroma of the tibial nerve. It was excised, and alcohol was introduced into the stump of the central segment. Pain continued to bother the patient. Acute hyperpathy was noted on the outside surface of the foot, and this is where the pain radiated when pressure was applied to the scar located on the lateral surface of the lower third of the shin. On 12/22, revision of the sural nerve was performed. It turned out to altered, as a result of which is was dissected. The spontaneous pains and pains during walking disappeared immediately.

The patient's wound did not heal for a long time as a result of osteomyelitis of the fibula. Moreover, there was a simultaneous injury to the distal end of the tibial and sural nerve.

Spontaneous pains and especially pains arising during walking were the basic complaint of the patient. These pains were eliminated by resection of the sural nerve.

On the basis of the presented illness histories with injury to the sural nerve, we may presume that this nerve plays a significant role in the mechanism of disorders arising with wounds to the lower third of the shin and the foot.

With injury to the sural nerve, N. B. Chibukmakhar observed a loss reminiscent of the picture of affliction of the entire sciatic nerve. A. I. Geymanovich, basing his information on observations conducted during the Great Patriotic War, affirms that with fractures of the femur, sensitivity disorders may occur in the innervation zone of the sural nerve. With injury to the sciatic nerve at the same level, these disruptions do not occur.

The femoral nerve. The anatomical proximity in the course of the femoral nerve to the femoral artery and vein explains the fact that usually trauma to this nerve is accompanied by simultaneous injury to the mentioned vessels, and most patients evidently perish from blood loss soon after sustaining their wound. This, possibly, explains the circumstance that injury to the femoral nerve, despite its considerable size and surface location, and represented by very low figures in the statistical data.

According to the materials for the development of illness histories, firearms injuries to the femoral nerve were noted in 1.6% of the cases. According to the materials of personal observations, injuries to the femoral nerve comprised 3.0%. According to the data published during the Great Patriotic War (N. Kh. Alekseyev, L. Ya. Brusilovskiy, S. I. Gorodetskiy, N. D. Zakharov, N. A. Iozefovich), the percentage of wounds to the femoral nerve fluctuates from 1.0 to 4.0.

The clinical picture of injury to the femoral nerve below the Poupart ligament was comprised, as we know, from the disruption in the function of shin extension in combination with a loss or reduction in the patellar reflex and disruption in sensitivity at the anterior surface of the thigh and the anterior interior surface of the shin.

A clear clinical picture of injury to the femoral nerve made it possible to pronounce a diagnosis without particular difficulty. A good test for trauma to the femoral nerve is the test of walking on a ladder: the patient with injury to the femoral nerve finds it difficult to ascend a ladder.

Of the other tests, let us note the following: 1) with paralysis of the femoral nerve, the kneecap is not fixed and may be freely moved to the left or right; 2) when the patient kneels, he tilts in the direction of his healthy side.

Complaints on the inability to extend the knee joint with the absence of expressed disruptions in the osteo-muscular apparatus evoke suspicion if there is an active patellar reflex.

With injuries located in the central third of the anterior /150 surface of the thigh, only part of the branches of the femoral nerve was affected. However, firearms injuries to this area often resulted in large gaping wounds which formed thick scars upon healing, spreading far into the interlayers between the heads of the quadriceps muscle of the thigh. Individual branches of the femoral nerve which were subjected to trauma fused into the scar tissue and gave symptoms of acute soreness. Atrophy of the muscles in these cases was usually incomplete.

The restoration of the femoral nerve, particularly after neurolysis of its trunk, proceeded rather favorably. Regeneration of the femoral nerve after suture of the primary trunk also yielded good results if there was no muscle fibrosis as described above.

The internal femoral cutaneous nerve. Isolated injury to the internal femoral cutaneous nerve was noted, according to the materials of personal observations, in 6 patients. With the exception of one patient, all of them had an injury at the level of the femur. The wounding in one case was accompanied by a sensation of "a blow to the leg", and in another "to the heel". A third patient experienced burning pains on the anterior-internal surface of the shin.

The primary complains in this group of patients was the spontaneous pain, and especially the pain arising when the wound scar is touched. A demonstrative example of this is the observation concerning a patient with a firearms injury to the soft tissue of the upper third of the thigh.

> With good muscular force of the wounded extremity, wounded patient P. complained that he could not walk because and movement causing clothing to touch the scar was accompanied by severe pains irradiating along the anterior-internal surface of the shin. Upon examination, a scar was found on the anterior-internal surface of the thigh which was painful

under pressure with the pain irradiation to the anterior-internal surface of the shin. Noted here was a reduction in pain and tactile sensitivity with pinching being acutely painful.

Acutely painful touching of the anterior-internal surface of the shin was also noted in patient T. He had a small ulceration on the anterior-internal surface in the upper third of the shin. During the operation, it was found that the external cutaneous nerve of the lower extremity was cicatrized. Upon palpation, an intra-trunk neuroma was discovered. After resection of the nerve the pains subsided, but the ulceration, which had healed before the operation, recurred.

In conclusion of the section on injuries to the nerve trunks of the lower extremities, it is necessary to touch upon the question of the significance of the cutaneous nerves.

A number of clinical observations devoted to injuries of the cutaneous nerves of the lower extremities have demonstrated their significant role in the mechanism of emergence of pains and trophic disorders which reduce the work capability of the injured extremity. Certain specifics of the clinical picture of injury to the sural nerve and the external cutaneous nerve of the lower extremity were presented in the section on injuries to the sciatic nerve.

The indications of A. G. Molotkov on the significant role of the posterior femoral cutaneous nerve in the mechanism of the emergence of pains and trophic disorders were also confirmed in the observations of V. L. Lesnitskaya and S. I. Gorodetskiy during the Great Patriotic War.

Injury to the posterior femoral cutaneous nerve was observed, according to the materials of personal observations, in three patients. Two of them had simultaneous injury to the sciatic nerve. The clinical picture was reduced to disruptions of superficial sensitivity on the posterior surface of the thigh. In two cases there were burning pains -- in one -- a trophic ulcer on the heel. The following observation is an illustration of this. It is also deserving of attention because the patient experienced a recurrence of the ulceration as a repercussion.

Patient A. sustained a wound to the soft tissue of the right buttocks region on 12/10/1941. Immediately the use of the foot was "lost" and burning pains appeared in it. After four months of hospital treatment, the patient was discharged to the convalescent batallion with subsequent assignment to the front. In 1943, an ulceration appeared on the heel of the wounded leg, which healed soon after repeated hospital treatment. The patient was discharged to his unit. In his words, the function of the foot was weakened and sensitivity in it was lost. On 2/2/1944 the patient was wounded in the stomach. Three days after this wound was sustained, an ulceration appeared on the heel, i.e., in the same place as in 1943. During an examination performed on 9/13, a deep trophic ulcer was found on the heel with purulent malodorous secretions. The plantar and dorsal flexion of the foot was satisfactory, and there was a "hint" at dorsal flexion of the toes. The achilles and plantar reflexes could not be evoked. Reduced sensitivity was noted on the external surface of the shin, anesthesia on the dorsal and plantar surface of the foot. On the posterior surface of the thigh there was a reduction in pain and tactile sensitivity with elements of hyperpathy (acutely painful pinching, unpleasant sensation with irradiation into the heel when the posterior surface of the thigh was touched). Soreness was also noted when pressure was applied to the thigh and shin along the posterior surface. /151

From the clinical analysis of injuries to the external femoral cutaneous nerve conducted in N. A. Krysheva on 50 patients it is evident that injury to the indicated nerve entails, aside from the sensitivity and trophic disorders in the zone of its cutaneous innervation, also repercussive disruptions in individual areas of the nervous system (changes in the eye slit, tendinous reflexes on the side of the injury).

The obturator nerve. Firearms injuries to the obturator nerve were observed in exceptionally rare cases -- with massive injuries to the inside of the thigh in its upper third, as well as in traumas to the pubic bone with sharp displacement of the fragments.

With intrapelvic injuries, almost complete paralysis of the femoral adducting muscles was noted, which hindered the adduction of the leg.

Changes in sensitivity with paralysis of the obturator nerve were insignificant. Sometimes it was possible to find a small area of hypesthesia in the region of the lower third of the thigh and along the inside of the knee joint.

With injuries to the internal surface of the thigh, the anterior branch of the obturator nerve was most often injured. Therefore, complete paralysis of the entire adducting musculature did not occur: only individual muscular groups were atrophied.

Restoration in the conductivity of the obturator nerve, as well as the clinical picture occurred differently, depending on whether pelvic or extra-pelvic injury was present. In the case of the former, the process was usually complicated by osteomyelitis, the times for the reconstructive operation were delayed and acute atrophy of the adducting musculature set in. With extra-pelvic injuries there was often the development of thick scars which constricted the adducting musculature.

The lumbosacral plexus and its branches. Wounded patients with injuries to the lumbosacral plexus were encountered at stages of evacuation as well as in rear line evacuation hospitals in very small numbers. The explanation for this should be sought in the fact that firearms injuries to the indicated plexus occurred as a result of severe traumas usually accompanied by the simultaneous injury to vessels, wounds to pelvic bones, and often with injury to the caval organs -- the large intestine, the rectum, the bladder.

We must presume that the overwhelming majority of these patients died either on the battlefield or on the first-second day after sustaining their wounds while in front-line stages of evacuation. These wounded patients were singular cases in rear evacuation hospitals, and were always among the very severe cases. The frequency of injury to /152 to the lumbosacral plexus as compared with other traumas to the nerve trunks was determined as 0.4% (O. V. Nazarova, K. P. Chikovani).

It is also necessary to note the localization of the wound at the exit point of the roots from the cerebrospinal canal. These wounds presented great difficulties for treatment, associated with the removal of shell and bullet fragments, foreign bodies, "secondary fragments" from the long muscles of the back.

In injuries to the lumbosacral plexus, partial or complete, phenomena associated with massive hemorrhaging were noted in the initial period. Therefore the clinical picture was expressed by complete paralysis of the entire lower extremity and the muscles of the pelvic girdle. The patellar and achilles reflexes were absent, disruption in sensitivity usually extended along the entire extremity. Sometimes accompanying disruptions in the function of the pelvic organs were observed, most often the inability to hold urine.

With partial injuries to the plexus, sensitivity of individual regions of the lower extremity appeared as the hemorrhaging was resolved, and the functions of the individual muscle groups were restored.

This made it possible to give a more precise diagnosis of the injury to the lumbosacral plexus, as well as to determine its character.

Additional x-ray studies made it possible to determine the character of the bone injury, the presence of foreign bodies which sometimes pressed on the plexus and which sometimes lodged directly in the roots of the latter.

In later periods, the course was often complicated by infection and often severe injury was observed to the lumbosacral plexus accompanied by ostitis and osteomyelitis of the pelvic bones and the spine.

Consequently, in the diagnosis and treatment of injuries to the lumbosacral plexus, the primary link became infection and the battle against it.

The difficulty in operative approach to foreign bodies in the area of the pelvic, the difficulty of operating on severe cases of osteomyelitis and opening pelvic abscesses often conditioned greater penetration of pus into the pelvic fatty tissue, whose drainage presented great difficulties. The subsequent spread of infection along the roots of the lumbosacral plexus conditioned the emergence of complications which were often the cause of the patient's death.

## Clinical syndromes with injuries to the nerve trunks

In the preceding chapter, the most constant indicators of firearms injuries to the nerve trunks were presented. Various combinations of these indicators comprise clinical syndromes which allow us to define more precisely the degree of disruption in nerve conductivity, and sometimes even to judge the character of the nerve injury (anatomical severance, neuroma, cicatrical change in the trunk and around it). The clinical syndromes which emerge with nerve trauma are not numerous. However, they are examined differently by different authors.

N. N. Burdenko isolates four syndromes (severance, compression, irritation, and restoration of the nerve), N. I. Grashchenkov isolates three syndromes (complete disruption of conductivity, partial disruption of conductivity, and irritation syndrome).

B. S. Doynikov isolates two forms of firearms wounds to the peripheral nerves (complete and partial disruption of conductivity). N. M. Itsenko adheres (as does N. N. Burdenko) to the following classification: the syndrome of severance, compression, irritation, and /153 restoration of the nerve. D. A. Krasnov proposed that firearms injuries to the nerve trunks be divided into seven groups: wounds to the nerve trunks (partial or complete disruption in their conductivity), contusion or crushing of the nerve trunk, compression of the nerve, irritation of the nerve, ascending neuritis, combined trauma to the nerve and vessels, and complication of nerve injuries caused by other disorders.

From the brief list of the proposed classifications published during the Great Patriotic War it is evident that most authors confuse clinical and morphological indicators in isolating the individual forms of nerve trunk injuries.

The syndrome of complete disruption of nerve trunk conductivity is characterized by paralysis of the muscles innervated by the injured nerve in combination with hypotonia rapidly increasing into atrophy and with the disappearance of tendinous reflexes. Immediately after injury, the electrical excitability of the central segment disappears, and by the end of the third day a complete degeneration reaction develops in the peripheral end of the traumatized nerve. There is total absence of trunk excitability in combination with acute elongation of muscle chronaxy, often with the subsequent complete loss of their excitability.

Anesthesia and hypesthesia are noted in the autonomous zone, often in combination with hyperpathy in the mixed zones of cutaneous innervation of the damaged nerve. Vascular and trophic disorders develop in uncomplicated cases in later periods and are limited to cyanosis of the hand, anhydrosis in the zone of innervation of the damaged nerve, hypotrichosis, brittleness and inhibited growth of the nails. Complete disruption in nerve trunk conductivity may be observe with full and partial anatomical severance, as well as with its contusion. The stability of the syndrome of complete trunk conductivity disruption, established by long-term observation, gives a basis for speaking of its complete anatomical severance. With slight contusions of the nerve trunk, its conductivity may be disrupted as a result of changes of a dynamic character (parabiosis) which occur within it, and is restored within several days after the injury. This form of injury is usually called nerve concussion.

The syndrome of partial disruption in nerve trunk conductivity is characterized by incomplete loss of function of the injured nerve, which is often accompanied by a partial degeneration reaction and extension of chronaxy. Of the sensitivity disruptions, its more differentiated aspects are usually lost: the sensation of

touch, localization, differentiating heat from cold, articulatory-muscular sensation (epicritical sensitivity) with retention of gross pain and temperature (protopathic) sensitivity. Spontaneous pains, as well as pain and paresthesia occurring during palpation of the nerve trunk distally from the point of trauma, are frequently noted with partial disruption in nerve trunk conductivity. Among the frequent indications of this form of nerve injury are also vascular and trophic disorders.

The syndrome of partial disruption in nerve conductivity is usually observed with partial anatomical severance and with various intra-trunk changes (hemorrhaging, neuromas, cicatrical changes), as well as with compression of the trunk by surrounding scars. In cases when the indicated changes are accompanied by irritation of the nerve trunk, pains in combination with acutely expressed and rapidly growing trophic and vascular disorders are predominant in the clinical picture. The symptom-complex of /154 irritation is usually particularly acutely expressed in patients whose nerve trunk injury is accompanied by causalgic syndrome.

The experience of the Great Patriotic War showed that with partial injury to the peripheral nerves, functional disruptions are usually observed in the entire nerve trunk. Sometimes the disruption of conductivity in individual trunk fascicles prevailed. This is particularly true of the sciatic nerve, whose partial injury was limited to disruption in the conductivity of its fibular and tibial portions.

If a pyogenic infection is present in the surrounding tissues, particularly in the presence of osteomyelitis, the nerve trunk injury may be complicated by the development of an ascending inflammatory process within it (ascending neuritis). Pains occur, often of a pulling or shooting character, with irradiation along the course of the nerve. Soreness appears upon palpation of the nerve trunk in a proximal direction from the point of injury. Locomotory disruptions in combination with muscle atrophy may develop in the same direction. Trophic and vascular disorders

also increase.

With simultaneous injury to the nerves and vessels, the clinical picture is comprised of indicators characteristic for nerve trunk injuries and ischemic disorders. The most severe form of this type of injury is Folkman's ischemic paralysis.

Two stages are usually distinguished in the development of ischemic paralysis. The first is characterized by edema of the distal sections of the injured extermities, limitation of movement, reduction in sensitivity, cyanosis, and reduced temperature in the injured extremities. Clearly manifested in the second stage is fibrose degeneration of the soft tissues (muscles, tendons, skin, subcutaneous fatty tissue). The atrophic muscles are hard. Active and passive movements are sharply limited, and in severe cases complete loss of active movements in the distal areas of the extremities is noted. Sensitivity disruptions are distributed by segmental type, growing in intensity in a distal direction. The extremity is cyanotic, cold, no pulse is felt on it, and anhydrosis is present. The skin is thinned, and persistent ulcers appear from insignificant injuries.

Along with this severe form, injuries to the neurovascular fascicle may be manifested by less acutely expressed disorders whose character and degree depend on whether the symptoms of injury to the vessels or to the nerve trunks are prevalent.

The restoration of functions lost as a result of nerve trunk injury takes place spontaneously or under the influence of treatment measures. This stage of restoration in nerve conductivity is characterized by a combination of indicators whose degree of expression determines the plan of treatment measures. In solving the problem of the need for operative intervention, the character and degree of expression of indicators showing conductivity restoration play a decisive role.

The first to be restored is the muscle tonus of the paralyzed muscles. After this, movement appears, first in the proximal segments; isolated movements (for example, in the interphalangeal articulations) are not restored for a long time with a background of good general movements. Atrophy disappears gradually with the growth of the locomotory function, with the transition of complete degeneration reaction into partial (often the degeneration reaction is retained for a long time, even when the arbitrarily willed motor function has been fully restored). The last to be restored are /155 the reflexes. Often they remain lost in the presence of complete restoration of the locomotory and sensitivity disorders. Sensitivity gradually appears in the zone of previous anesthesia, first gross pain sensitivity, which is easily discernable by pinching the skin in the area of previously absent sensitivity.

Epicritical sensitivity (the sensation of touch, localization, differentiating heat from cold, articulatory-muscular sensitivity) is restored later. At the same time, hyperpathy gradually disappears. Among the earliest indications of regeneration are pains, spontaneous paresthesia, as well as paresthesia caused by pressure along the course of the nerve trunk, but distally from the point of its injury.

Aside from establishing the degree of disruption in nerve trunk conductivity, it is also important to clarify the level of injury to one nerve or the other. An examination of the point of injury, the course of the wound channel, does not always make it possible to determine the level of trauma to the nerve trunk, particularly in cases where there are multiple wounds. The character of the clinical picture of nerve trunk injury at various levels plays a significant role in solving this problem. It is also necessary to compare the clinical data with the anatomical course of the nerve trunk, particularly with the level of divergence of its main branches.

Is is possible and necessary to clarify the character of nerve trunk trauma (clarification of morphological changes arising in the nerve trunk resulting from their firearms injury based on clinical examination)? The experience of the Great Patriotic War confirmed the generally accepted position that there is no complete parallelism between the disruption in physiological conductivity of a nerve and the character of disruption in its anatomical structure. Basec on this position, certain clinicians feel that in order to develop a plan of treatment, particularly for substantiating the necessity of operative intervention, it is sufficient to establish the degree and stability of disruptions in nerve trunk conductivity. A macroscopic examination of the nerve with subsequent electrodiagnostics on the operating table makes it possible to clarify the degree of disruption in conductivity, as well as to judge the macroscopic morphological changes within it. This serves as the basis for selecting the type of operative intervention (nerve suture, neurolysis).

Speaking out against this "oversimplified approach" is S. N. Davidenkov, who feels that it is possible to compile a more precise idea of the character of the injury before the operation and to define more precisely the proposed type of operation. The comparison of data from neurological and surgical study with consideration of the topographical location of the wound, the direction of the wound channel, the extent and severity of the injury, the course of wound healing and the dynamics of neurological symptoms -- all help to make a more precise diagnosis.

Complete restoration in nerve trunk conductivity within several days after the wound is sustained allows us to exclude any structural changes in the nerve trunk.

We may speak of the presence of such changes (partial anatomical severance, contusion with subsequent hemorrhaging, formation of scars inside or around the trunk) if gradual restoration of the lost functions is observed within the course of weeks or months after the injury.

The growth of symptoms indicating nerve trunk conductivity loss or nerve trunk irritation is usually an indication of the nerve being compressed by scars, aneurism, or bone callous. The /156 stability of symptoms of complete disruption in nerve conductivity for approximately 2-3 months after the injury allows us to suspect complete anatomical severance with a known degree of certainty, without fully excluding the possibility of macroscopic integrity of the trunk with severe intra-trunk changes within it.

Based on comparison of the clinical picture with the data from macroscopic examination on the operating table of injured nerves in 800 patients, came to the conclusion that it is possible in a considerable percentage of cases to determine the character of macroscopic changes before operative intervention. The author made wide use of the methodology of palpating the traumatized nerve trunk in combination with data from dynamic neurological study. In all cases, thorough electrodiagnosis was performed before the operation as well as on the operating table.

With injury to the osteo-muscular apparatus, as well as with long-term immobilization of an injured extremity, functional disorders arise which may be taken as manifestations of nerve trunk trauma. A number of works is devoted to the clinical picture of injury to the osteo-muscular apparatus. Of these, we must note particularly the observations of T. D. Uporov. Unlike the clinical picture characteristic for nerve injury, in these cases locomotory disorders are observed within limited margins due to rigidity; movements are painful, and with active and passive movements the scar is often painfully pulled. Atrophy is not limited to a definite group of muscles, as is observed with nerve injuries; reflexes and electrical excitability are not disrupted, and a slight loosening of the contractures and reduction in tonus may be observed under anesthesia. If the pains occur along the course of the muscle or scar rather than along the course of the nerve trunk, sensitivity disruptions are usually not observed during palpation. If they are noted, they are weakly expressed and reduced to a loss of pain sensitivity or hyperesthesia in the area of the wound, and sometimes

spread to the zone of cutaneous nerves involved in the cicatrical process. The articulatory-muscular sensation remains intact. Trophic and vascular disorders are not related to constant indicators of the clinical picture with injury to the osteo-muscular apparatus. If all these disorders occur (edema, increased perspiration, cyanosis), then their degree of expression is insignificant.

For the purpose of differentiating locomotory disorders which depend on wounds to the nerves or muscles, M. N. Brotman successfully used faradic current. The stimulation of the muscle belly causes its contraction and a stretching of the scar in a proximal direction. When there is injury to the tendon, only the stumps of the damaged muscle contract.

After the First World War, a primarily "wait and see" tactic was established in regard to treating patients with trauma to the peripheral nerves. This conservatism was disproven by the experience of the Great Patriotic War, which showed that early diagnosis of nerve injury with subsequent energetic treatment, including operative intervention, significantly accelerated the restoration of work capacity lost as a result of the nerve trunk trauma.

We have often had occasion to study patients with nerve injuries several hours after their wounds were sustained. Swelling of the distal regions of the injured extremity, often in combination with the absence of movement in the fingers, and sometimes the hand or the foot, did not permit us to speak with assurance of injury to one nerve or the other. During wound treatment it was sometimes possible without a special search to establish the character of macroscopic changes in the nerve trunk. However, 2-3 days later, /157 clear indications of nerve trunk damage became apparent. Particularly valuable were the studies of pain sensitivity and articulatory-muscular sensation.

According to the proposal by A. V. Triumfov, patients were subjected to neurological study whose traumatized extremity was already placed in a cast and only the digits remained free. Subsequent observations showed that in a considerable percentage of these cases it was possible to determine the injury to one nerve or another.

Disruption in sensitivity on the back of the hand and in the primary phalanges of the first two and a half fingers in combination with the absence of extension and abduction of the thumb testifies to trauma of the radial nerve.

Sensitivity disruptions on the dorsal surface of the V, IV and partially the III finger, and on the palmar surface -- the V, partially the IV finger with disruption in flexion of the fifth finger and adduction of the thumb, as well as loss of articulatory-muscular sensation in the fifth finger are characteristic for injury to the ulnar nerve.

Sensitivity disruptions on the dorsal surface of the end and central phalanges of the first two-and-a-half fingers and the palmar surface of the I, II, III and partially the IV finger in combination with loss of function in flexion of the end phalanges of the I and II and disruption in articulatory-muscular sensation in the index finger are observed with injuries to the median nerve.

Sensitivity disruption on the back of the foot with absence of dorsal flexion of the toes is characteristic for injury to the fibular nerve. Sensitivity disruption on the sole of the foot and the dorsal surface of the terminal phalanges with disruption in plantar flexion of the toes is characteristic for injury to the tibial nerve. Sensitivity disruption on the back and sole of the foot in combination with loss of articulatory-muscular sensation in the toes and absence of any movement in the toes is observed with trauma to the sciatic nerve or with simultaneous injury to both of its terminal branches.

Two to three weeks after the injury is sustained, the diagnostic task is reduced to clarifying the degree of injury on the basis of neurological study. X-rays are used to clarify the presence and localization of the foreign body (bullet, shell fragment, piece of bone). In a later period, 2-3 months after the injury, it is possible to judge to a certain degree the presence or absence of regeneration. In the case of absence or defect in the regeneration process, it is necessary to clarify the reason for this. The most reliable data on the degree of injury, as well as on the presence or absence of regeneration are obtained as a result of neurological study with the use of electrodiagnostic data, including chronaximetric. The most reliable data on the character of the trauma to the nerve trunk and on the reasons for difficulty in regeneration are obtained during clinico-surgical study, including a macroscopic examination of the nerve during its revision.

## CHAPTER II

## FIREARMS INJURIES TO THE CRANIOCEREBRAL NERVES /158

N. N. Burdenko pointed out that firearms injuries which penetrate the base of the skull usually have a fatal outcome and the patients, as a rule, do not reach the hospital. In the course of the First World War, of 3,020 cases of cranial injuries N. N. Burdenko observed only 12 patients with firearms inflicted fractures of the base of the skull accompanied by symptoms of injury to the cranio-cerebral nerves. Of these, only three were evacuated in satisfactory condition. The others died.

During the Great Patriotic War, the organization of specialized neurosurgical aid made it possible to save the lives of such patients. Therefore, injuries to the intracranial portions of the cranio-cerebral nerves were observed more frequently. Nevertheless, they were rarely noted, particularly in the acute period of trauma, and in a number of cases became apparent later as complications resulting from secondary post-traumatic processes.

Deserving of particular attention are those sections of the cranial nerves where the latter leave the skull through the opening in its base. As we know, these areas in the skull are considered to be the least stable during trauma. In the anterior cranial fossa this is a cribiform plate of the ethmoid bone through which the olfactory nerve pass into the nasal cavity. At the anterior boundary of the middle cranial fossa, the second pair nerves pass through the optical orifices. Passing through the upper eye slit are the oculomotor nerves (III, IV and VI) and the first branch of the trigeminal nerve. At the bottom of the middle cranial fossa, the second branch of the V nerve leaves the cranial cavity through a circular orifice, and the third branch exits through the oval orifice.

The facial nerve, before leaving the stylomastoid orifice, passes passes through the long route in the osteal bed of the pyramis and the mastoid process, accompanied in the internal acoustic meatus by the acoustic and the intermediate nerve. Although the mastoid process is a strong osteal mass on the boundary of the middle and posterior cranial fossa, it does not protect the pyramis against comparatively frequent fractures. In the posterior cranial fossa, the glossopharyngeal, vagus and accessory nerves leave the cranium through the large jugular foramen, while the hypoglossal nerve exits through its own channel.

The listed anatomical specifics explain the frequent injury to the cranial nerves with closed traumas complicated by fractures of the base, since cracks and fracture lines pass along the base of the skull through the thinner sections of bone weakened by the presence of orifices. The close proximity between the roots of the individual nerves and the constancy of their interrelations at various sections of the intracranial path condition clear typical syndromes with various types of fractures.

Thus, it is well known that if a fracture line passes through /159 the body and the large wing of the main bone and a fragment presses on the optical orifice and the upper eye slit, the sphenoidal slit syndrome may occur on the side of the trauma: blindness, complete ophthalmoplegy and disruption of sensitivity on the foreheat (injury to the II, III, IV and VI nerve and the first branch of the V nerve). If the fracture line encompasses the anterior lacerated opening, then phthalmoplegy, pains and anesthesia in the area of the supra-orbital nerve may be accompanied by deafness from the rupture of the eustachian tube. Fractures of the pyramis and the temporal bone involving the V, VII, VIII and the intermediate nerve into the injury are accompanied by sensitivity disruption on the face and tongue with taste disruption, paralysis of the mimical musculature, vestibular disorders, and disorders of lacrimation and salivation. Fracture of the bottom of the posterior cranial fossa encompassing the posterior lacerated foramen and the articular process of the

occipital bone may cause the syndrome of the indicated four nerves with paralysis of half of the soft palate, pharynx, larynx, tongue, sternocleidal and trapezoidal muscles with disruption of taste in the the posterior third of the tongue and sensitivity disruption in the corresponding half of the soft palate, pharynx, and larynx.

For the anatomical specifics of the extracranial portions of the nerves, there is a characteristic division of the trunks into their peripheral branches, a more dispersed course of these branches, the connection of numerous nerves with the sensory organs, which determines their position in the eye socket, nasal or oral cavity, or in the ear. The proximity of the nerves on the neck to the major internal organs is very significant. These topographical relations determine the fact that injury to the nerve branches is an ingredient in the more massive injury to the face or neck and therefore rarely gives a picture of dominant neurological syndrome, particularly in the acute period when the symptoms of injury to the individual nerves are masked by other more vital disorders (vision,swallowing, breaching or brain damage).

The indicated circumstances explain the fact that in the acute period, trauma to the nerve branches may pass unnoticed. To a certain degree this is evidently due to the low frequency of firearms injuries to the craniocerebral nerves which is reported in summarized statistical data. There are no exact numerical data to characterize the frequency of injury to the cranial nerves in works which reflect the experience of the past wars.

According to the materials for the development of illness histories, wounds to the cranial nerves comprise 0.15% of all injuries to the peripheral nerves. These figures will increase if we add to them the statistical data of otorhinolaryngologists and ophthalmologists which reflect disorders in olfaction and heating with craniocerebral wounds and injuries to the optic nerve with wounds to the eye socket.

The olfactory nerve often suffered with closed and open trauma to the cranium, bur its injury was apparent only with special examination. According to the data of V. I. Bersemenovskiy based on military materials, weakening of olfaction in the acute period of cranial trauma was noted in 15.5%. I. M. Rozenfel'd considers anosmia an almost constant companion of all penetrating wounds in the area of the frontal sinuses with injury to the frontal lobes. Based on the material of rear area institutions, N. S. Blagoveshchenskaya established olfactory disruption in 60.0% of the cases of penetrating cranial wounds with injury to the frontal lobes. In 1/3 of these cases the disruptions were unilateral, in 2/3 they were bilateral. The loss of olfaction was noted somewhat less frequently than its reduction. Olfaction suffered with particular frequency in injuries to the cribriform plate, while its loss was usually accompanied by disruption in the integrity /160 of the dura mater. Frequent olfactory disruptions with craniocerebral injuries were noted by O. G. Ageyeva-Maykova, Yu. D. Arbatskaya, S. M. Kompaneyets and others. In cases of closed trauma, A. R. Polyakov during methodical research established olfactory disruptions in the acute period dependent on injuries to the primary olfactory formations (olfactory filaments, bulb, tracts) in 23.0% of the cases. Anosmia was noted in 4.0% and hyposmia in 19.0%. Olfactory disruption accompanied severe closed trauma and fractures in the anterior cranial fossa. Differences of opinion as to the frequency of injury to the first nerve pair depend on the material available to authors in connection with the character of the trauma, its location and severity. Nevertheless we must believe that the first pair of cranial nerves suffers more often than is discovered, particularly since hyposmia and even anosmia often do not attract the attention of the patients.

Olfactory disruption was caused by a break in the olfactory nerves, as well as by hemorrhaging or swelling. In the latter cases the disorders arose or grew in the next few days following the trauma, but were not severe and transitory.

With firearms wounds to the frontal and orbital regions, the olfactory nerve was often injured. Observed at the same time were injuries to the branches of the oculomotor nerves, the first branch of the trigeminal nerve, and the temporal branches of the of the facial nerve. From the illness histories presented below it is evident that unilateral or bilateral anosmia was a constant companion to penetrating frontal wounds. Injury to the olfactory nerves does not require special treatment.

Injury to the optic nerve occurred with firearms inflicted trauma to the cranium if the destruction or cracks in the bone encompassed the optic canals, but more often the nerve was injured with wounds to the eye socked. Here the trauma was accompanied by a direct affliction of the nerves, their compression by bone fragments, shell fragments or hematoma. More often there were contusions of the nerve, hemorrhaging within its thickness, and less frequently it was severed.

With wounds which destroyed the orbit, the optic nerve was usually injured together with branches of the VI, IV and III nerve. Within the confines of the optic canal, the nerve together with the ophthalmic artery closely adheres to the osteal walls, and its hard tunic performs the role of a periosteum. Therefore in this area with traumas to the base of the skull, hemorrhaging in the intertunic space occurred quite easily, causing temporary or permanent blindness. Penetrating wounds conditioned the compression of the optical tracts by hemorrhaging, bone fragments or metal chips, being correspondingly manifested by tractal hemianopsia (I. O. Merkulov).

Secondary traumatic neuritic of the optic nerve occurred with injuries to the sphenoidal sinus and with purulent meningitis. Of the later, although rare, complications, post-traumatic optico-chiasmic arachnoiditis deserves attention. In this case, surgical intervention in the form of commissure division and opening of cystic cavities leads to improvement (N. N. Burdenko, B. G. Yegorov,

A. V. Skorodumova).

Trauma to the motor nerves of the eye -- the oculomotor, the trochlear, the abducent -- were most often associated with fire-arms wounds to the orbital cavity, and were more rarely observed with penetrating cranial wounds. These injuries were accompanied by damage to the bones in the area of the superior orbital fissure or fissures in the base of the skull. The trauma caused direct injury to the branches, their contusion, compression by bone or metal fragments, hemorrhaging, etc. With injuries to the orbital cavity, the injury to the eye motor nerves was associated usually /161 with injury to the eyeball, muscles and vessels of the eye socket. Isolated oculomotor paralyses or pareses were observed rarely and were manifested usually in later periods. Disruption in movements was the result of simultaneous contusion to the muscles. Observed as a consequence were ptosis, strabismus, and diplopia. Total affliction of the oculomotor nerve was conditioned by contusion with fracture of the eye socket tegmen. Simultaneous injury to the III, IV and VI nerves was observed with damage in the area of the superior orbital fissure and was accompanied by the above-mentioned sphenoidal fissure syndrome. Cases of trauma to the eye motor nerves on their path along the subarachnoidal space with penetrating wounds diagnosed in a later period were exceptionally rare. Isolated injury to the oculomotor nerve at the base of the brain was described as a causistic case by Ye. Z. Tron. A case of paralysis of the III nerve with lodging of a fragment in the middle cranial fossa was presented by Zn. M. Kaminer.

As an example of severe injury to the eye socket with manifestations of paralysis of the III nerve, we may present the following case, which at the same time also illustrates the injury of the first pair.

Wounded patient N-ov, 34 years old. On 3/23/1945, the patient sustained an open bullet wound to the right superciliary region with the exit wound in the left zygomatic region. There was a prolonged loss of consciousness and loss of substantia

medullaris. The wound was treated on 3/26 with partial removal of bone fragments. There was damage to both frontal lobes of the brain, the frontal sinuses, the orbit, the left ethmoidal labyrinth and the left eyeball. On 4/15, meningeal phenomena developed. On 4/18 the patient was admitted to the Institute of Neurosurgery in serious condition. There was abundant purulent secretion from the fistula in the right superciliary region. Bilateral anosmia was present. There was ptosis of the left eyelid, the left eyeball had been crushed. There was edema of the optic papilla on the right side. The patient exhibited flaccidity, retardation. There was an increased amount of protein in the cerebrospinal fluid. X-rays showed a comminuted fracture of the internal wall of the left eye socket with damage to both frontal sinuses and cribrate cells. On the right there was a defect in the superciliary region. The diagnosis: purulent-polypose sinusitis, subdural abscess. On 4/23 frontal-ethmoid trepanation was performed, along with the removal of all bone fragments and drainage of the subdural abscess. There was a gradual regression of meningeal and psychopathological symptoms. Anosmia and ptosis of the eyelid remained unchanged. On 5/23 the patient was discharged in good condition.

In this case there was an extensive firearms inflicted fracture of the frontal and ethmoid bone with crushing of the eye and destruction of the frontal lobes. The severe course was complicated by purulent sinusitis and aubdural abscess. With a background of gross trauma and severe overall condition, disruptions on the part of the first and third nerve pairs (complete anosmia and ptosis) could not attract attention at the preliminary stages of evacuation. They were established only with systematic study at the Institute of Neurosurgery, but even here they had no significance either for evaluation of the patient's condition or for selection of the method of treatment.

Injury to the trigeminal nerve was most often observed with firearms wounds to the face -- less frequently with penetrating cranial wounds. Isolated injuries of branches of the V nerve were also encountered in combination -- injury to two and three branches. The first branch of the trigeminal nerve is involved in the process more often than the others. Its isolated injury was usually observed with wounds to the eye socket, and particularly with destruction of the supraorbital edge. The frontal and supraorbital nerves were

injured together or separately, giving a corresponding zone of anesthesia. The pressure of a fragment or scar was manifested by pains and hyperesthesia and could serve as an indication for intervention. With injury to the first branch more proximally to the entrance into the eye socket, sensitivity disruption was joined by the loss of corneal reflex, and in later periods neuroparalytic keratitis occurred.

The second branch of the trigeminal nerve was injured with /162 wounds to the eye socket with destruction of its lower wall or with wounds to the upper jaw. Damage to the infraorbital nerve with anesthesia on the cheek (S. A. Chugunov) was considered characteristic for transverse fractures of the upper jaw. If in the early period after treatment of the wound, a foreign body remained deeply wedged in the maxillary sinus causing sharp pains, the need arose for another operation (G. G. Kulikovskiy and M. M. Filippov). Stubborn infraorbital neuralgia in later periods were often explained also by pressure on the nerve caused by bone fragments and foreign bodies (B. N. Lebedevskiy) and served as an indication for intervention.

Trauma to the III branch was most often associated with maxillary-facial wounds, when it is very difficult to evaluate the motor function of the nerve in connection with splinting, edema, and defects in the soft tissues. With fractures of the horizontal branch of the lower jaw, the alveolar branches were damaged, which was manifested by hypesthesia or hyperesthesia on the chin and lower lip. With injury to the ascending branch, the oto-temporal branch was involved. Then the zone of sensitivity disorders spread forward from the floor of the auricle and into the region of the temple. The syndrome of sensitivity disorders was observed with participation of the lingual nerve, when the disruption in cutaneous sensitivity was joined by disruption of sensitivity and taste on the anterior two-thirds of the tongue. With wounds to the deep sections of the facial area, injuries were observed to the sensory and motor branches. Here, most chewing

muscles cannot be retained.

Damage to the more proximal segments of trigeminal nerve branches was most often associated with penetrating cranial wounds accompanied by destruction or fissures in the bottom of the middle cranial fossa. Slighter contusions, as well as compression of the branches by hematoma in the acute period of craniocerebral trauma might remain unrecognized. The observations of L. I. Pressman are interesting in this regard. He studied the sensitivity of the nasal mucous membrane with penetrating cranial wounds. He found a stable reduction in the sensitivity of the nasal mucous membrane in 51.0% of the cases with retention of normal cutaneous sensitivity on the face. Such a microsymptom may indicate the indirect participation of the trigeminal nerve. With more gross injuries to the intracranial sections, disruption on the part of the branches of the V nerve are expressed clearly and enter into a number of symdromes mentioned for closed trauma. They are characterized by a typical picture of sensitivity disorders, disruption of the corresponding reflexes from the mucous membrane of the eye or nose, and with the participation of the third branch -- paralysis of the chewing musculature on the corresponding side.

In the later period the scarring processes conditioned the emergence of stubborn neuralgia. Even causalgic syndromes have been described in the area of the individual branches (S. A. Chugunov), as well as a number of vegetative disruptions with post-traumatic neuritis of the trigeminal nerve branches. The Gasserian ganglion was also involved in the process of later scarring, presenting a picture of severe neuralgia.

Ye. Zh. Tron described a rare case of neuroparalytic keratitis which developed on the basis of scars around the Gasserian ganglion 8 months after a firearms wound to the V nerve.

With pain syndromes, a therapeutic effect may be given by heat treatments, novocaine blocks and other conservative measures used in treating pain.

In stubborn cases of neuralgia it may become necessary to /163 perform operative treatment including the application of retrogasserial root severance or tractotomy (B. G. Yegorov).

The illness history presented below serves as an example of the destruction of the peripheral branch of the trigeminal nerve, which may easily be overlooked in the acute period with the severe condition of the patient.

> On 12/29/1943, wounded patient B. sustained an open penetrating bullet wound to the left temporal region with the exit wound in the right frontal region. There was prolonged loss of consciousness and loss of substantia medullaris. The wounds were treated on 12/31 with removal of bone fragments and cerebral detritus. Both frontal lobes were damaged, as well as the frontal sinuses and the left eyeball. On 1/14/1944 the patient was admitted to the neurosurgical evacuation hospital. Objectively: on the right side above the eyebrow was a fistula with purulent secretions, on the left side -- a granulating wound. There was psychic disruption according to the frontal type. There was bilateral anosmia and blindness of the left eye (traumatic iridocyclitis). Anesthesia was present on the right half of the forehead, and hypotonia of the extremities. There was central paresis of the facial nerve and vegetative disruptions. The protein content in the cerebrospinal fluid was elevated. X-rays showed on the right side a destruction of the upper orbit wall and frontal sinus; on the left in the temporal region there was a defect with smooth edges. On 2/17, repeated wound treatment and frontal-ethmoid trepanation were performed. On 4/21 the patient was discharged in good condition with stable anosmia and anesthesia on the right side of the forehead.

In this case of bilateral frontal injury, special examination revealed bilateral affliction of the right pair and unilateral affliction of the first branch of the trigeminal nerve. This case may illustrate the injury of several craniocerebral nerves, which depends on the course and extent of the wound canal. In this

patient, extensive brain damage and severe purulent complication prevailed, which is what engaged the attention at the preliminary stages as well as in the rear area. Injury of the first branch with anesthesia on the forehead had no significance for the evaluation of the patient's condition and did not bother him later.

In the next case, extreme attacks if trigeminal pains served as the reason for repeated hospitalization of the patient.

> On 3/25/1945, wounded patient N. received a blind penetrating wound to the right frontal-orbital area with injury to the eye socket, the eyeball and the frontal sinus. The wound was treated on 3/30 with gradual healing. On 9/20 the patient suddenly experienced an attack of pain in the right frontal region and in the right half of the face. On 10/11 he was admitted to the Institute of Neurosurgery with a diagnosis of post-traumatic neuralgia of the first branch of the trigeminal nerve. Objectively: anosmia on the right side, hypesthesia in the region of the first and second branch of the trigeminal nerve on the right side, acute soreness at their exit points, diffuse soreness in the right frontal region. There was a change in psyche according to the frontal type. X-rays showed on the right side a post-operative defect of the frontal bone encompassing the superior wall of the eye socket. On 10/14 the patient's condition worsened, his temperature was 38°, there was swelling in the right superciliary region. On 10/16 the epidural abscess was drained. The patient's condition improved and the pains stopped.

In this case, 7 months after the injury with destruction of the superior margin of the orbit, attacks of neuralgic pains appeared. Objectively, of the cranial nerves there turned out to be damage to the I nerve (unilateral anosmia) and the V nerve (hypesthesia in the area of the first and second branch). The soreness at the exit points of the nerves, the attack-like character of the pains and their late appearance forced us to think of the irritation of the nerve branches by scars. However, the reason for the irritation turned out to be the purulent epidural process. After draining the pus, the pains stopped.

Injury to the facial nerve and its individual branches was observed quite often, which is explained by the topographical specifics and clear manifestation of its loss. The subcutaneous course of the branches on the face conditions the possibility of their isolated injury with contusions of the face and with superficial wounds in the temporal, zygomatic, buccal, and submaxillary regions. With injuries to the parotid gland, there is noted a more massive involvement of the branches with injury of the upper and lower trunks or the entire plexus. Firearms wounds to /164 the mastoid process which comprise, according to V. I. Voyachek, from 6.0 to 10.0% of cranial injuries, and according to A. A. Shlykov -- 4.7% -- are quite frequently accompanied by injury to the facial nerve trunk. The latter occurs even more often with firearms damage to the pyramis and with fractures of the skull base, with which A. N. Kartavov noted the participation of the facial nerve in 44.0%.

Depending on the character and depth of the injury, paresis and paralysis of various extent, intensity and stability would occur. The level of injury to the trunk was determined, as we know, by clinical symptomatology. Thus, for example, with injury in the posterior section of the fallopian canal, paralysis of the facial musculature is accompanied by a disruption in taste (the participation of tympanum cord fibers). With injury above the m. stapedius, hyperacusia is added, with injury at the level of the gangl. geniculatum -- a disruption in lacrimation. The facial nerve was often damaged in combination with other cranial nerves: with traumas of the pyramis -- with the V and VII nerve, with injuries to the retromandibular region -- with the IX, X, XI and XII nerve.

After contusion of a nerve or its branches there was a gradual spontaneous restoration of movement. In order to facilitate speech and chewing impediments and prevent the development of contractures, it is recommended that the facial muscles be supported in proper position with the aid of adhesive bandage strips (according to Z. I. Geymanovich) which narrow the eye slit and pull the corner of the mouth and cheek upward. The bandage is changed every 1-2 days until

tonus is restored and movement appears, which occurd in 2-3 months (G. D. Novinskiy). At the same time, various forms of physical therapy, parafin application, electrization, massage, etc. are recommended. The data of electro-excitability or chronaxy are very important in selecting therapeutic measures and for prognosis. In a considerable number of cases, paralyses are restored with conservative treatment. Thus, according to P. N. Bulatov, physical therapy yielded successful results in 25 out of 35 cases.

In a number of cases of firearms inflicted paralyses complicated by osteomyelitis of the temporal bone, the function of the facial nerve is restored after operations directed toward the treatment of osteomyelitis (Ya. S. Temkin). Paralyses of the nerve often depend on cicatrical compression within the boundaries of the soft tissue or mastoid process. In such cases, neurolysis may lead to the restoration of movement. Based on the material of the First World War, N. N. Burdenko noted only the partial success of neurolysis. Operations with the isolation of the nerve endings from the bone canal within the mastoid process, displacement and convergence of the ends with application of a suture or insertion of a small transplant have been successfully used in recent years and have numerous supporters (B. G. Yegorov, Zh. L. Kalina). With extensive damage to the temporal bone and the impossibility of application of a direct suture, anastomosis of the facial nerve with the sublingual or accessory nerve is applicable. Movement appears 3-6 months after anastomosis application: first concomitant, then arbitrary. After a year, the concomitant movements begin to diminish and facial symmetry is restored. The end results, despite the absence of fine mimical movements, according to the experience of the Institute of Neurosurgery imeni Acad. N. N. Burdenko, must be considered very good (B. G. Yegorov). The anastomosis operation in patients with residual stable paralysis of the facial nerve has been used many times with great success (B. G. Yegorov). Singular cases have been described by P. N. Bulatov.

Hypertonia of the mimical muscles or tic muscle twitching /165 in the form of hemispasm may develop as a residual phenomenon after trauma to the facial nerve.

Presented below is a case of persistent paralysis of the VII nerve disfiguring the patient, in which an anastomosis operation gave excellent cosmetic effect.

> On 1/14/1943, wounded patient V., 28 years old, sustained a blind fragment wound to the left mastoid process. There was prolonged loss of consciousness, complete peripheral paralysis of the facial nerve. The wound was treated several days later. The wound healed after prolonged suppuration. there was repeated irritation of the cornea of the left eye. On 10/22/1945, the patient was admitted to the Institute of Neurosurgery imeni Acad. N. N. Burdenko. Objectively: in the area of the left mastoid process there was a retracted scar. There was leucoma on the left eye and absence of corneal reflex, accompanied by hypesthesia of the first and second branch of the trigeminal nerve on the left side. There was total peripheral paralysis of the left facial nerve with lagophthalmia and salivation from the left corner of the mouth. Speech was unintelligible. There was absence of taste on the anterior two-thirds of the tongue and loss of the auditory function on the left side. Electrical excitability was absent in all the branches of the facial nerve. The operation was performed on 12/10: on the left the branch of the accessory nerve leading to the sternocleidomastoid muscle was dissected and sutured to the peripheral end of the dissected facial nerve. Six months later, concomitant movement appeared (when the arm was raised, the facial muscles contracted). After 2 years the concomitant movements became dissociated, the face became almost symmetrical, atrophy in the facial muscles was reduced, and arbitrary mimical movements appeared. There was subsequent progress in this improvement.

This case of a firearms inflicted fracture of the temporal bone differs in that, aside from total paralysis of the facial nerve, the injury left a partial disruption of the first and second branches of the trigeminal nerve, which complicated the course of the wound period by keratitis. Anastomosis of the facial nerve with the accessory gave excellent functional results, which is confirmed by numerous observations of the Institute of Neurosurgery imeni Acad. N. N. Burdenko of the AMN SSSR.

Disruption of the auditory and vestibular function of the VIII nerve due to firearms wounds to the temporal bone as well as generally with open and closed cranial traumas, has been noted very frequently. According to the data of A. A. Slykov, middle parabasal wounds (with injury to the temporal bone) comprised 4.0% of all penetrating craniocerebral wounds. According to the data of G. S. Tsimmerman, with craniocerebral injuries, ear trauma comprised 5.0%, but when we consider the effect of barotrauma in wounded and contused patients, the number of cases with auditory disruptions grows to 90%. O. G. Ageyeva-Maykova found that with cerebral wounds, auditory disruption is the most frequent symptom. However, auditory reduction and vestibular disruptions were less dependent on direct injury to the nerve trunk than on trauma to the sound perception apparatus, the semicirculan canals, or on the participation of the corresponding systems of the brain.

Isolated wounds to the glossopharyngeal nerve were rare, but sometimes occurred with wounds caused by small fragments. Most often the IX nerve suffers together with the X and XI nerves during fractures which encompass the posterior lacerated foramen, or with injuries to the retromandibular region under the base of the skull. Zh. M. Kaminer cides a case of an isolated injury through the mouth, when a fragment the side of a millet seed passed behind the larynx and the esophagus and lodged in the body of the III cervical vertebra, damaging the pharyngeal branch along the way. At first the patient noted trouble in swallowing and hoarseness. Two months later there remained a sagging of the soft palate, its delay during phonation, and a reduction in the palatal reflex. With injuries to the horizontal branch of the lower jaw, injury was noted to the glossopharyngeal nerve with participation of the vagus, and with simultaneous trauma to the lower branch of the facial nerve. This /166 caused corresponding paralysis of the mimical musculature, the muscles of half the soft palate and the pharynx (Chugunov's submandibular syndrome). With bilateral injury of the glossopharyngeal nerve, the act of swallowing is impossible, and the patient must be fed through a tube. In the later period, cicatrical processes

around the nerve may lead to the emergence of a pain syndrome of a unique neuralgic type.

Injury to the vagus nerve was observed with fractures of the base of the skull, when usually this nerve was injured simultaneously with the IX, X, and XI nerves. More often the trauma was caused by firearms wounds to the neck, where the nerve was involved at a different level with traumas of various localization: with wounds to the mastoid process, the lower jaw, the retromandibular fossa the upper section of the trunk was damaged; with lower wounds to the lateral surface of the neck, the trunk was involved after it diverged from the superior laryngeal nerve and only the recurrent branch suffered. The deep position of the vagus nerve along the exit from the jugular foramen, where the nerve is fixed on the prevertebral fascia, conditioned the possibility of simultaneous injury to the vertebrae. At a lower level, where the trunk is located behind the large vessels of the neck and is displaced together with the vascular fascicle, its injury it observed with wounds to the carotid artery and with the later development of aneurisms.

Trauma to the vagus nerve was manifested by paralysis of the larynx on the same side, hoarseness, paroxysmal tachycardia, and arythmia. Severance of the nerve presents no particular dangerous. Irritation of the trunk with a fragment or hematoma may give a more serious picture with rarification of breathing up to its complete cessation and cardiac arrest in diastole. In this case, immediate operative intervention is necessary at the first stage of evacuation.

Isolated wounds were noted to the upper laryngeal or recurrent nerve. The first was expressed by anesthesia of the corresponding half of the larynx and slight coughing, the second -- by characteristic hoarseness. With bilateral injury to the recurrent nerve there was severe disruption in breathing of the inspiratory dyspnea type, in which case tracheotomy is indicated.

The accessory nerve was injured in its intracranial section as well as immediately upon its exit from the jugular foramen, usually together with other neighboring nerves. Distally along the neck it is possible to have isolated injury of the trunk or its individual branches to the sternocleidomastoid or trapezoid muscle. Injury of the nerve leads to a slight tilt of the head to the well direction, a drooping of the shoulder, a slanted position of the scapula and atrophy of the innervated muscles. However, as a result of additional innervation of the latter by the second to the fourth cervical root, the manifestations of loss were not severe, atrophy was usually weakly expressed, and functional disruptions were practically insignificant. In the later period when the nerve was irritated by scars, convulsive contracture (torticollis) developed.

Injuries to the intracranial portion of the sublingual nerve with fractures at the base of the skull and cervical injury of this nerve immediately upon its exit from the sublingual canal were usually combined with injuries to the IX, X, and XI nerve. Isolated injury to the nerve was caused by wounds to the retromandibular fossa or in the submaxillary retion, in the oral cavity, and with firearms inflicted fractures of the horizontal branches of the lower jaw. Contusions, hemorrhaging and infiltrates around the nerve causes pareses which were transitory or remained in the form of slight traces. Gross injury to the nerve was manifested by /167 paralysis of the muscles of the corresponding half of the tongue, followed by their subsequent atrophy.

Cue to their close anatomical proximity, the four latter cranial nerves were often injured together, giving a syndrome of caudal nerves indicated above for fractures of the bottom of the posterior cranial fossa. Neck wounds were also accompanied by injury to these nerves in various combinations with the participation of the facial, certival sympathetic or thoracoabdominal nerve, as well as roots of the cervical or brachial plexuses, depending on the course of the wound channel. A. I. Zlatoverov described two

characteristic syndromes with nerve injury on the neck: the upper -- with wounds in the super-sublingual region (suprahyiodal), and the lower -- with injuries below the level of the sublingual bone (infrahyoidal). With the bormer -- a blind or open neck wound with the entrance or exit opening at the angle of the lower jaw or at the margin of the sternocleidomastoid muscle caused Horner's symptom, hoarseness, slight paresis of the soft palate, atrophy of half of the tongue with disruption of taste on it. In some cases there was also paresthesia encompassing half of the head and neck and dependent on the participation of the sympathetic nerve. With injury to the lateral surface of the neck below the level of the sublingual bone, Horner's symptom was observed, there was paresis of the vocal cords, affliction of the roots of the cervical or the upper roots of the brachial plexuses and paresthesia encompassing half of the head, neck, the arm, and the upper part of the chest (involvement of the sympathetic nerve). If there was no foreign body lodged on the vagus nerve, the pulse at rest did not give any sharp fluctuations, but under load there was a sharp increase in heartbeat and dyspnea. Paralysis of the diaphragm was established in intividual cases by x-ray. When the roots of the brachial plexus were involved, a picture of Erb's paralysis was noted.

In recognizing injuries to the cranial nerves, as in injuries to nerves of the extremities, the primary leading factor is the place of injury and the direction of the wound channel. With a precise consideration of the topagrapho-anatomical data, it is often possible to make a preliminary tentative diagnosis. In the acute period, elementary neurological study of sensitivity and movements is not always possible due to the presence of the wound, hemorrhaging, swelling, and the severe condition of the patient. Therefore, complaints of sharp pains, swallowing disorders, problems in phonation, etc. deserve attentive evaluation. In the later period, recognition of injuries to the cranial nerves does not present much difficulty if the local wound process or its consequences do not mask the disruption of the nerve functions.

Operations in the case of cranial nerve injuries were performed at the preliminary stages of evacuation according to vital indicators and with severe cases of nerve compression by fragments and bullets. Operations on nerve restoration were not performed under front conditions. In a later period the pains caused by the pressure of fragments, infiltrate, pus or scars on sensitive nerve could lead the surgeons to take action. Interventions of a restorative character in the presence of indicators were possible in specialized rear area hospitals. Most often indicators for operation are pain syndromes resulting from the involvement of the nerve into the scar, and in less frequent cases -- disfigurement of the face, as occurs with paralysis of the facial nerve. Paralyses caused by severence of the remaining cranial nerves, being unilateral, did not lead to severe disability and were usually not subject to surgical treatment.

## CHAPTER III

## SURGICAL TREATMENT OF FIREARMS WOUNDS TO THE PERIPHERAL NERVES /168

### Indications, counterindications and times for operative intervention in peripheral nerve injuries

The history of the question of the indications and times for operative intervention in peripheral nerve injuries begins with the period of the First World War, since in preceding wars there were few nerve trunk injuries.

At that time, the "wait and see" tactics were generally accepted. The earliest times for operations were considered to be 4-6 months after the injury was sustained. These time-tables were then adhered to by N. N. Burdenko, A. L. Polenov, V. N. Shamov, A. Yu. Sozon-Yaroshevich and numerous others. This was explained by the following circumstances: a) the fear of infection; b) a significant number of cases of spontaneous nerve restoration; c) a completely erroneous conception of the fact that basically indications for operation are presented only after verification of the morphological character of the nerve injury (its severance) and with the condition of absence of regenerative indication.

However, very soon many of our surgeons and neurosurgeons began proposing the principle of earlier surgical intervention (N. N. Burdenko, V. N. Shamov and others). At the end of the First World War, the substantiated principle of early surgical intervention on a nerve was first presented by Pavlovskiy (1916) and at the same time by V. I. Razumovskiy (1916), later by V. R. Braytsev and others.

For approximately 20 years after the First World War, the question of the indicators and times for nerve operations was studied in this country primarily on the basis of materials of everyday domestic trauma (N. N. Burdenko, Z. I. Geymanovich, A. L. Polenov, A. Yu. Sozon-Yaroshevich, V. N. Shamov and others). During this same period, the series of experimental and morphological studies (B. S. Doynikov, P. K. Anokhin, B. I. Lavrent'yev and others) significantly determined the further development of the question, confirming the necessity of early contact of the central and peripheral nerve segment for full regeneration. The significant effectiveness of earlier times for operations was shown by V. A. Goykhman, I. S. Babchin, and D. G. Gol'dberg.

Comprehensive studies of electroexcitability before and during the neurolysis operation, when the solution to the question of nerve conductivity retention was difficult, made it possible to more precisely determine the condition of nerve trunk conductivity and clarified indications for individual types of operative intervention. The war with the White Finns, the battles around Lake Khasan and at Khalkhin-Gol were accompanied by a small number /169 of extremity wounds with nerve trunk injury. During the period of these combat operations, our country's surgeons clearly demonstrated a desire for earlier operative intervention (N. N. Burdenko). The works published immediately prior to the Great Patriotic War and the work conducted by A. D. Speranskiy in studying regenerative capacities of the nerve are interesting. It was established that the best restoration of conductivity of the peripheral nerve is achieved with suture application either 6 hours after the injury or 4 months later. A. D. Speranskiy does not give an explanation for this regularity. In any case, based on the material of numerous authors it was made evident that the operation on the peripheral nerve must be performed either in the first 6-12 hours after the wound is sustained, or after the wound has healed within a time not to exceed six months. Of course, if the patient were admitted to neurosurgery at a later time, the operation should

be performed, but its results would be less effective.

Thus, by the beginning of the Great Patriotic War, all the theoretical assumptions were present for the possible reduction of waiting times. However, the leading factor remained the necessity of establishing the diagnosis of anatomical severance and the degree of injury. Complete wound healing was considered a necessary prerequisite for operative intervention on the nerve trunk.

During the Great Patriotic War, preliminary nerve suture was applied very rarely. This was associated with the maneuvering character of military operations, during which it was difficult to perform planned preliminary treatment, and it was futile to apply preliminary suture to the wound. However, in cases where specialized neurosurgical institutions were close to the front, as for example in Leningrad, the preliminary nerve suture was used in rare cases (A. G. Molotkov, A. Yu. Sozon-Yaroshevich). The same was often observed in the periods of calm and in hospital army bases. Under these conditions, special indications for the application of preliminary suture were worked out.

Despite the great experience in treating firearms injuries to the peripheral nerves in the course of the Great Patriotic War, the question of times for surgical intervention is not yet fully solved. It is still unclear whether an operation is indicated in the first hours after the wound is sustained, or whether preference should be given to operative intervention at a later time. Despite an entire series of experimental works and works on peripheral nerve surgery during domestic trauma which convince us of the expediency and substantiation of early operations on damaged nerves, the combination of wartime trauma with a series of particular conditions sharply limits the indications for early operative intervention. These limitations are so serious and grave that a large number of advocates for early interventions during the period of the Great Patriotic War could not be found.

We should consider it an established fact that the question of expediency of early intervention on a damaged nerve may be presented only with its partial or complete severance.

However, we must reiterate the position stated by I. Ya. Razdol'skiy as early as 1939 which has not lost its significance even now, after the publication of a number of theoretical and practical data arguing in favor of the expediency of early diagnosis and early suture of a traumatized nerve. I. Ya. Razdol'skiy maintained and still maintains the totally correct viewpoint that a diagnosis of nerve severance may be made only by means of clinico-surgical analysis. He says: "The neuropathologist who takes upon himself the task of deciding the question of the character of trauma in the presence of loss in the function of a damaged nerve, i.e., the task of deciding the presence of absence of complete /170 or partial nerve severance, goes beyond the limits of capability of his method, fooling himself and confusing the surgeon, since complete loss of nerve function may be observed with retention of the nerve trunk continuity, with total retention of its axons, and in the first hours after nerve injury even with its concussion. With the presence of total loss of nerve function in the first 24 hours, the question of the character of nerve injury may be answered only by examination of the nerve".

This position as well as a study of the materials of the Great Patriotic War allow us to quite definitively characterize the indications for surgical intervention and the time when it should be performed.

In view of the difficulties of neurological diagnosis in the first hours after a firearms wound to the peripheral nerves, operations should be indicated on traumatized nerves with application of suture for restoration of their integrity only in the following cases: 1) when a foreign body or bone fragment is found in the nerve trunk or lies on it, causing intolerable pain; 2) when the

trunk of the injured nerve is exposed along its path due to simultaneous injury of a blood vessel (pulsation, hematoma, hemorrhaging); 3) when surgical treatment of an extensive zone of injury in the wound also encompasses the area of the neurovascular fascicle.

With these three forms of injury, suture application on the damaged nerve trunk is indicated. Patients with all other forms of firearms injuries to the peripheral nerves are directed to rear line institutions, but with the mandatory condition of proper splinting of the extremity. It has been established that the first 1½-2 months should be considered the observation period, which coincides with the time necessary for the wound to heal. This time, according to the data of our country's histologists (B. S. Doynikov and others) will be indicative for the beginning of regeneration if the nerve injuries are reversible, or in this time there will be convincing evidence of the irreversibility of the damage (anatomical severance).

In the indicated period with the aid of the neurological and electrodiagnostic method it is already possible to determine the degree and character of disruption in the conductivity of the nerve trunk, but morphologically the character of the injury remains unclear.

In those cases when by the end of the first month there appear initial, even partial, signs of regeneration, surgical intervention should be considered premature, and all accessible methods of conservative treatment should be forcefully conducted. If, on the other hand, no signs of restoration of conductivity appear during this period, while processes of atrophic changes in the muscles become apparent, surgical treatment should not be delayed. However, the indicated periods are regularly applicable only in those cases when significant complications on the part of the wounds are absent. With purulent complications, all manifestations of regeneration may be detained by the growing

scars and extensive changes in the surrounding vessels and muscles. In such cases, the modern surgeon, armed with antiseptics and antibiotics, need not wait, but may be guided by early indications favoring intervention as soon as the suppurative process subsides in the wound channel.

Based on these data, it is necessary to stress that in general, operative interventions during the Great Patriotic War were performed in early periods after the injuries were sustained -- before 6 months, which is evident from table 18.

Table 18 /171

Times for operative interventions in regard to firearms injuries to the peripheral nerves

| Time of operation | Percentage of cases |
|---|---|
| Before 1 month | 2.22 |
| " 2 months | 11.80 |
| " 3 " | 24.60 |
| " 4 " | 26.50 |
| " 5 " | 17.80 |
| " 6 " | 9.90 |
| " 8 " | 5.90 |
| " 1 year | 1.20 |
| " 2 years | 0.01 |
| Over 2 years | 0.07 |

It is evident from table 18 that operations for peripheral nerve injuries were performed in the first 3 months after the wound was sustained in 38.6% of the cases, and in the first six months after wounding -- in 92.8% of the cases. These figures are a clear testimony to the high surgical activity in the early periods after firearms injuries are sustained.

Going to details, it should be noted that indications for indicators and times for this intervention are conditioned by numerous factors in individual patients. Primary among these we must place the character of the injury: was complete anatomical severance observed or was it a matter of physiological severance, was nerve compression present, was nerve trunk irritation of the causalgic type observed? Further, indications were determined by the condition of the wound, the degree of infection, and the overall condition of the patient.

According to the materials for the development of illness histories, operative interventions on individual nerve trunks were performed at various times (table 19).

It is evident from table 19 that wounds to the nerve trunks of the upper extremities were subjected to operative interventions at earlier periods than those of the lower extremities. The latter, along with other conditions, also depended on the extent of the wound and the duration of wound healing. It should be noted that operative interventions in earlier periods were more often performed with injury to the median and ulnar nerves than to the radial, and with injury to the sciatic nerve -- more frequently than to the tibial and fibular. Operations were more rarely performed early with combined nerve trunk injuries.

Thus, the extensive material of the Great Patriotic War enables us to conclude that early periods of operative intervention with peripheral nerve injuries have been approbated by wartime practice. Indications for early periods of operation with nerve trunk injuries constitute one of the basic conclusions stemming from the experience of the Great Patriotic War in the area of firearms wounds to the peripheral nerves.

At preliminary stages of evacuation with closed as well as with open firearms fractures when there was simultaneous nerve

trunk injury, operations on the latter were not indicated. In rare cases when the patient was brought in during the first hours after sustaining the wound and in the presence of appropriate conditions, there was indication for thorough surgical dissection of the wound followed by reposition of the displaced pieces and /172 application of a primary epineural suture with subsequent blind closure of the wound and application of a cast. It should be noted that with firearms bone fractures accompanied by nerve trunk trauma, the treatment of the fractures was basic.

Table 19

Times of operative intervention after firearms wounds to individual peripheral nerves (in percentages)

| Name of nerve | Time of operation | | | |
|---|---|---|---|---|
| | before 3 months | from 3 to 6 months | from 6 to 12 months | over 1 year |
| Brachial plexus.... | 40.5 | 46.0 | 5.4 | 8.1 |
| Radial..... | 38.5 | 51.6 | 6.5 | 3.4 |
| Median..... | 48.8 | 41.3 | 5.0 | 4.9 |
| Ulnar..... | 45.3 | 45.4 | 7.3 | 2.0 |
| Radial and median.. | 28.6 | 58.7 | 9.5 | 3.2 |
| Ulnar and median... | 35.6 | 57.6 | 3.8 | 3.0 |
| Radial and ulnar... | 31.8 | 68.2 | -- | -- |
| Radial, median and ulnar..... | 30.3 | 58.8 | 7.9 | 3.0 |
| Sciatic..... | 37.4 | 51.5 | 9.0 | 2.1 |
| Tibial..... | 21.1 | 68.4 | 5.2 | 5.3 |
| Fibular..... | 28.0 | 61.3 | 6.7 | 4.0 |
| Sciatic and femoral | 16.7 | 83.3 | -- | -- |
| Nerves of the upper and lower extremities | 23.1 | 53.8 | 7.7 | 15.4 |

As evidenced by personal observations, in a number of cases there was noted a delayed consolidation which was evidently associated with nerve trunk injury. Undoubtedly, in these cases

it is necessary to consider operation also on the nerve trunk indicated in order to change the neurotrophic factor to the favorable side.

A significant part of firearms inflicted fractures was complicated by osteomyelitis, and in these cases restorative operation on the nerve was postponed indefinitely.

At the same time, observations of wounded patients with osteomyelitis showed that in the period of the active inflammatory process in the bone -- the formation of sequesters and fistulas -- the nerve does not show any signs of regeneration in conductivity even when the nerve trunk is not severed, but merely involved in the center of the inflammatory changes. A vicious circle was created: infection of the bone led to irreversible changes in the nerve, while the afflicted nerve, affecting the bone trophics, detained consolidation of the fracture and liquidation of the osteomyelitic center.

A series of works has appeared (D. S. Zel'dich, N. M. Ipenko, A. S. Lur'ye, A. G. Fetisova) which presented the question of the indications for surgical intervention on nerve trunks in known infected and osteomyelitic centers. Kirsanova, on the basis of her material on 40 cases of combined nerve and bone injuries complicated by osteomyelitis and in which she used simultaneous operative intervention on the nerve and the bone, came to the conclusion that such tactics improved the course of the osteal process and the regenerative capability of the nerve in a number of cases.

Thus, during the Great Patriotic War, indications were presented for simultaneous operative intervention on the nerve and on the bone in the presence of osteomyelitis. However, /173 most surgeons during this war were of the opinion that the osteo-

myelitic process first had to be liquidated, and then the operation performed on the nerve. As an exception, indications were sometimes presented for initial operation on the nerve in the presence of osteomyelitis in order to affect the neurotrophic factor (A. N. Bakulev). At the modern level of medical knowledge with the widespread practical application of antibiotics, early indicators must be presented for simultaneous intervention on the bone and the nerve. Early reposition and preliminary nerve suture combined with preliminary wound treatment will become the basic intervention with these types of combined injuries.

The combination of injury to the vessel and nerve created unique indications for operative treatment. At the preliminary stages, all the attention of the surgeon was concentrated on the necessity of stopping the hemorrhaging, which created immediate indications for ligation of the blood vessels. Vascular suture was practically not used and was considered non-indicated. The vessel was ligated in the wound or even along its extent and often was not cut, which caused irritation of the vasoconstrictors and worsened even more the blood supply to the extremity deprived of a main vascular trunk. Operative interventions on nerve trunks in such cases were performed very rarely. Thus, B. V. Petrovskiy, having at his disposal the material on 499 operations on main vessels of the extremities in firearms wounds, notes that "he did not look specially for severed nerve trunks, and sutured them only if they were present in the wound". Thus, although with combined injuries to the vessels and nerves interventions on the vascular system were often performed in the first days and weeks (secondary hemorrhaging), the question of indications for preliminary nerve suture was not presented. In the subsequent course of the wound process the injured extremity was in poor conditions, which in particular inhibited the regeneration of the wounded nerve. The insufficient blood supply to the extremity was joined by wound infection. This created the prerequisites

for delaying the process and for the development of a stable sclerosis of the muscles, fixation of the extremity in certain positions. The latter is conditioned by paralysis of the muscle groups innervated by the damaged nerve. It should be noted that in these cases indications for operative interventions were often presented with considerable delay. At the same time, the presence of an irritating center in the neuroma led to vascular spasm, deteriorating the blood supply to the extremity to an even greater degree. The nerve suture in the anemized extremity did not give full regeneration (A. Yu. Sozon-Yaroshevich). Therefore in such cases, as well as for combatting causalgia, sympathectomy was indicated, as it is after an operation on the peripheral nerve.

With the presence of deep ulcers or edemas, such sympathectomy was undertaken before the operation on the peripheral nerve for the purpose of expanding the vascular anastomoses (N. I. Makhov). According to the materials of personal observations, after such operations there was considerable swelling of the back of the hand, ulcers on the forearm which had not healed for months became closed, etc. However, operations on the vegetative nervous system were performed during the Great Patriotic War by a small number of surgeons (A. N. Bakulev, I. S. Babchin, A. V. Bondarchuk, B. G. Yegorov, M. G. Ignatov, F. M. Lampert, N. I. Makhov, N.I. Plotkin, G. A. Rikhter, A. Yu. Sozon-Yaroshevich and others).

The experience of the Great Patriotic War allows us to draw conclusions in regard to combined injuries to the vessels and nerves. Already at the first stages of evacuation, conditions must be created for the application of a vascular suture for /174 the purpose of providing the regenerating nerve with full vascularization. If this possibility was not provided, vascular ligation was performed with the section or, even better, with the removal of part of the vessel. There were broader indications for operations on the sympathetic nervous system with evidence of acute insufficiency of blood supply to the extremity.

With operative interventions on the nerve in later periods, indications always arose for the examination of the neighboring artery and vein. With the presence of severe cicatrical degeneration of the vessels, there were direct indications for their removal if the separation of the vessels from the scars became a difficult operation. Sometimes a useful and fully indicated procedure for purposes of expanding the vascular network was the operation for removing adventition from the artery. Thus, the injuries to the vessels changed the indications for operations on the nerve trunks and created worse conditions for nerve regenerating, reducing the trophics of the tissues. Nevertheless, in these combined cases, operative interventions on the nerve trunks were indicated in comparatively early periods.

Finally we must pause on the later period. This time, and namely 5-6 months after the wound is sustained, makes it possible to give a deeper neurological analysis of the nerve injury and the secondary changes in the support-motor apparatus of the extremity. Neurological studies in this period make it possible to determine projecting pains, disruption of protopathic sensitivity, change in muscle tonus, disruption of the motor function and finally, changes in electrical excitability. If it is neurologically possible to establish the presence of functional restoration, this serves as a counterindication to surgical intervention. Otherwise an operation is necessary. Finally, if there are signs of poor axon regeneration accompanied by a slight restoration in function, the presence of sharply expressed pain symptom, severe trophic, vasomotor, secretory and reflex disorders, the operation should be considered indicated. The goal of such an operation is to eliminate the obstacles to axon growth.

The question arises as to whether or not reconstructive operative interventions on nerves should be considered admissible when the course of the wound process was lengthy, the zone of injury was large, when the wound has pitted, torn, infected edges and has undergone lengthy suppuration, the necrotic tissue separated

for a long time and the restoration of the wound with formation of a rough scar constricting the extremity lasted an equally long time. In these cases, despite the diagnosis which requires operative intervention on the nerve trunk, it is necessary to wait for the wound to heal.

Some surgeons (B. G. Yegorov, Ye. V. Luk'yanova, A. Yu. Sozon-Yaroshevich and others) strongly recommended that intervention on the nerve trunk be performed 2-3 months after the wound is sustained, anticipating that the wound would be cleansed by this time. Unfortunately, after severe injuries, the wounds would still have traces of purulent complications during this time. In contradiction to this proposal, so-called "super-early" interventions were performed, which gave fair results (A. N. Bakulev, A. G. Neklepayeva, A. G. Fetisova and others) with the broad application of modern antiseptics. However, this methodology of early interventions did not receive unanimous acceptance. Infection of the nerve trunk was quite possible. Therefore, indications for such interventions must be rather limited, and often the latter should be considered counterindicated. N. N. /175 Burdenko wrote in this regard: "The possibility of the flare up of infection is always real, its spread is possible ... and finally ascending neuritis. It is presumed that, undertaking the operation before closure of the wound, the time of one month is gained. Is the loss for the nerve wound healing process so great with late operation, and would we not win in time at the price of risking the flare up of infection?"

With this purpose, B. G. Yegorov performed bacterialogical studies of the nerve scar and the wound passage in 50 cases during operations on nerve trunks and plexuses. In 64.0% of the cases he established sterility of the scar, and in 36.0% -- the presence of non-pathogenic staphylococcus. These important data allowed the surgeon to dispense with the accepted long waiting period after healing of the wound.

At the same time it is necessary to consider the fact that the suppurating wound abounds in products of tissue disintegration and toxins which, according to the study conducted by B. S. Doynikov and M. O. Gurevich, inhibit the regeneration of the nerve trunks. Therefore, the indicator for surgical intervention at an early time, in the opinion of these authors, must generally be the presence of foreign bodies -- bone or metal fragments causing nerve compression, and severe pain symptoms with causalgic overtones. Sometimes the presence of a false articulation or severe osteomyelitis dictated intervention on the nerve with the purpose of restoring the normal neurotrophic factor (A. N. Bakulev).

Summarizing operative interventions performed on nerve trunks after firearms wounds with the presence of infection, we must stress that these interventions were in their overwhelming majority performed in periods of up to 6 months and only in a small number of cases -- from 6 to 12 months.

## General characteristic specifics of the structure of the peripheral nervous system

In the period of the Great Patriotic War there was an apparent multiplicity of the clinical picture with peripheral nerve injuries. The relative frequency of injuries to individual nerves, their combined injuries with vessels and bones, varying symptomatology with monotypical injuries and similar symptomatology with injuries at different levels, as well as numerous other facts are explained in the specifics of the peripheral nerve structure, in their topographo-anatomical relations to the surrounding tissues. These specifics are individually variable. We know that, along with the description of the anatomical "norm", researchers and surgeons in particular have noted a large number of different anomalies and deviations from the norm. An example may be the large number of deviations from the usual location of the nerves found on the operating table. These deviations are essentially only

different manifestations of the norm. From this standpoint, the primary task of each topographo-anatomical study is to establish the range of variability in the regions, organs and systems studied. The clarification of marginal forms of variability is undoubtedly also useful. Knowing the specifics and characteristics of form variability, it is easy to imagine all the multiplicity observed in clinical practice and on the operating table.

Extreme forms of variability reflect individual inconsistency in the structure and position of the nerves. They are viewed from the standpoint of historical and evolutionary method /176 (comparative anatomy and embryology) and a consideration of the effect of the surrounding environment. The determination of extreme forms of variability is not a goal in itself, but rather, as has been indicated above, it serves to give an understanding of the range of differences in peripheral nerve injuries observed in clinical practice. Thus, this viewpoint has practical directionality and is aimed at enabling the physician to clearly understand the limits "from and to" within which the observed variations in the placement and structure of the nerves may fluctuate.

We must note that the word "extreme" or "marginal" does not signify the volume and the final limits, but is taken from the statistical terminology of constructing a variational series for the given anatomical material (extreme left and extreme right). Therefore extreme forms characterize the differences (variability) observed only on the presented anatomical material, and may vary in the same way as the entire series which they represent. Here it is necessary to consider the non-uniformity in the development of individual systems or even a single system in different areas (V. N. Shevkunenko).

At important moment is the practical significance of anatomical data. Each area has its own specifics of injury, its own clinical specifics. Thus, in studying the peripheral nervous system it is necessary to consider the clinical "individuality" of the individual nerve trunks which depends greatly on the specifics of their anatomical structure. Morphological studies must reflect this, they must explain the observed differences, and they must serve as the basis for practical conclusions.

In order to understand the topographo-anatomical data presented below, let us briefly pause on certain elements of the modern state of the question concerning the development, understanding of complexes, course of axons, etc.

The peripheral nervous system consists basically of conductors which connect the central nervous system with the organs and tissues. This functional connection leads to the fact that the position and external structure of the nerve trunks is often determined by the development of the peripheral organs. We know that each myotome, dermatome, etc. is supplied by three neurotomes: one basic and two neighboring. In some cases these conductors run in a single fascicle, and in others -- in several individual trunks. In those regions of the human body where in the process of development the segmental character of the periphery has relatively little disruption (for example, the thoracic region), the path of the axons to the terminal territories is almost linear. The connections between the individual nerves are weakly expressed and are represented primarily by fibers from the above-mentioned neighboring segments. In other areas, (for example, in the extremities) as a result of the displacement of myotomes and the multisegmental placement of the tissues, the axon paths are more complicated. Numerous connections are observed between the individual nerves which testify to the passage of the axons from the composition of one nerve to another.

The segmental (radical) generality of the nerves determines the possibility of replacing them with a neighboring nerve, increasing the territory of distribution, since the axons may reach the terminal territories primarily within the composition of a single nerve or in the composition of another or, finally, in the composition of both.

The differences in nerve structure in the same area observed in various individuals are a reflection of complex processes of phylo- and ontogenesis. However, this changeability is not random. Between the nerves of a given group there is a dependence in the sense of the expression of one or another trunk, its position and zone of supply. Therefore the study /177 of the peripheral nerves must be as comprehensive as possible, considering the supply of the area as a whole, beginning with the plexuses and ending with their peripheral branches. A group of such nerves which are genetically related and have a common segmental (radical) affiliation, is called a complex (V. N. Shevkunenko, A. N. Maksimenkov and others). Aside from this, the formation of the peripheral nervous system is influenced by the surrounding environment, which is particularly sharply expressed at an early age. In this respect, the variability in the distribution of nerves of the hand characteristic to humans attracts attention.

One of the basic differences in the structure of the peripheral nervous system is the connection between the individual nerves which is expressed to varying degree. Three types of intersegmental connections are distinguished: intradural, extradural proximal (in the area of the plexuses) and extradural peripheral (between the individual nerves). The most complex forms of these connections are the "arches", "loops" and recurrent branches. With one extreme form of variability, the connections are observed in great numbers, and in another they are insignificantly expressed.

Thus, the basic specifics of the external structure of the peripheral nerves are the differences in their radical affiliation, in the level of formation, expression of individual trunks, as well as in the character of branching, the degree of isolation (the number of connections) and the sphere of distribution.

The radical affiliation, the character of branching and the degree of isolation are all general indications of differences between all the nerve trunks of the extremities. The others are characteristic only for individual nerves -- particular indications.

Thus, particular indications for the musculo-cutaneous nerve are the differences in the expression of the trunk (sometimes it is completely absent) and in the area of its distribution. For the median and tibial nerves it is the level of formation and division into terminal branches with a relative constancy in the area of distribution. For the fibular, radial and ulnar nerves it is primarily the inconstancy in the zones of cutaneous innervation. For example, the "classical" distribution of branches of the radial and ulnar nerve on the dorsal surface of the hand with the dividing line passing through the axis of the middle finger is observed in approximately 1/3 of the cases. Much more frequently the radial nerve is predominant in the presence of expressed zones of displacement and overlapping. For the femoral, obturator and posterior cutaneous nerve of the femur, partial indicators are the differences in the character of branching and the area of distribution. These facts were reflected in the study of clinical practice of firearms wounds to the peripheral nerves.

It is interesting that the morphological individuality of nerves is manifested not only in the external, but also in the intra-trunk structure. Thus, according to the data of S. S. Mikhaylov, between the musculo-cutaneous and the median nerve

on the brachium there is an inversely proportional dependence in axon distribution: the more there are in the musculo-cutaneous nerve, the less in the median and vice versa. There is also observed a certain regularity in the content of various caliber fibers. For example, in the median nerve there is a greater number of small and medium pulpous fibers than in the ulnar nerve. In general, the most variable nerve in the upper extremity is the musculo-cutaneous, and in the lower -- the external femoral cutaneous nerve. Moreover, it is important to note the specific /178 feature characteristic for nerves of the upper extremity which is manifested in a significant increase in the number of connections between them in the direction of the distal segments, particularly in the area of the hand.

The structural specifics of the peripheral nerves described below conditioned the uniqueness of the clinical picture with firearms injuries to them and were sometimes the reason for a change in plans for operative intervention.

## Anatomo-topographic specifics of the nerves of the upper extremities and their significance in operative access

The experience of the Great Patriotic War showed that nerve injuries on the upper extremities were observed over 1½ times more frequently than on the lower extremities. Thus, from the data obtained in the development of illness histories it is evident that 61.0% goes to nerve injuries of the upper extremities and only 38.3% to nerves of the lower extremities. This is explained by the different relationship of a number of major nerves with the other anatomical elements of the extremities, by the specifics of the interrelation of nerve trunks with bones, etc.

We must also note that on the upper extremity there are more complex topographo-anatomical relations between the nerves

and the formations surrounding them, a closer interlacing with the major arteries and veins. This is particularly true of the brachial plexus. The position of the latter, its close connection with the numerous nearby vital formations, particularly with the venous trunks and the venous "lakes" developing after injury, make operative intervention on the brachial plexus difficult and dangerous. For the proper selection of the most convenient operative approach in each individual case and for successfully overcoming the difficulties which arise during surgical intervention, it is necessary, along with other conditions, to have a precise knowledge of the topographo-anatomical details. This necessitates giving particular attention to the anatomy of the formation in question and to the differences in the structure of the plexus and nerves.

The brachial plexus. The basic nerves comprising the brachial plexus are the branches of the sixth, seventh and eighth cervical roots. The fifth cervical root always plays a part in the formation of the brachial plexus, but often also gives a fascicle to the cervical plexus. The first thoracic root enters into the composition of the brachial plexus only partially. In almost half the cases (according to K. A. Grigorovich) the fascicle of the fourth cervical root is also included in the plexus. In this case the upper margin of the plexus is moved upward, which is noted with cranial displacement (fig. 58). In other cases, the plexus is displaced caudally, and then its formation includes the second thoracic, and at the top -- only part of the fifth cervical root. This is observed in almost ¼ of the cases. Connections of the second thoracic root with the brachial plexus may be expressed differently (fig. 59).

Cranial or caudal displacements of the plexus explain the various muscle paralyses with injuries to one or another nerve trunk and, on the contrary, identical paralyses with injury to

different trunks. Thus, in cases of a high beginning of the plexus, a wound to the fifth cervical root may be accompanied by injury not only to the deltoid, biceps and brachial muscles, but also to the radial extendor of the hand, the brachio-radial muscle, the supinator and the roung pronator. The same injury in cases where the plexus starts from the lower roots /179 may have no effect on the function of the latter four muscles, and even the biceps and brachial muscle may suffer only partially (K. A. Grigorovich). Here it is necessary to consider the specifics of the connections, their presence or absence.

The second moment of significance for a description of the brachial plexus is the connection between its trunks. Thus, the fifth cervical root is connected at a sharp angle with the sixth cervical roon, forming an upper primary trunk which, with a high beginning of the plexus, is comprised not of two, but of three roots (the fourth, fifth, sixth cervical). The eighth cervical root is connected with the brachial portion of the first thoracic, forming a lower primary trunk. When the plexus starts low, the composition of the latter includes the second thoracic root. The seventh cervical root is located between them as the middle primary trunk.

Each of the primary trunks is divided into two branches: /180 the anterior and posterior. The anterior branch of the upper primary trunk is connected with the anterior branch of the middle trunk, forming a secondary external trunk. Branching off the latter is the musculo-cutaneous nerve and the external "foot" of the median. The anterior branch of the lower primary trunk is designated as the secondary internal trunk, which gives the internal "foot" of the median nerve, the ulnar nerve, as well as the internal cutaneous nerves of the shoulder and the forearm.

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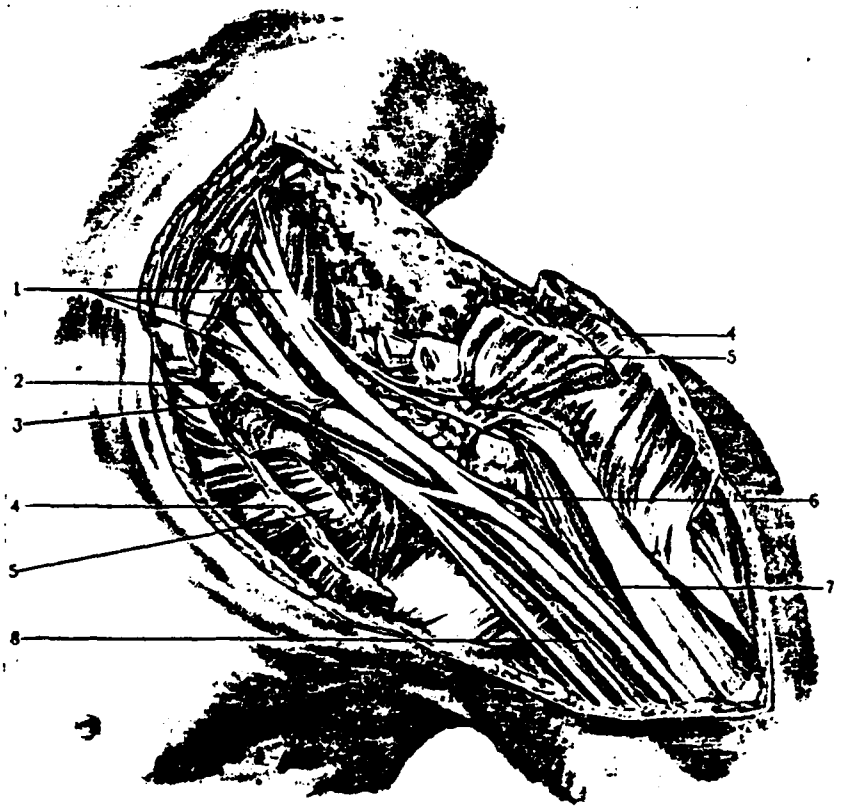


Fig. 58. The brachial plexus with cranial displacement (according to Grigorovich).

1 - the trunks of the brachial plexus; 2 - the subclavial vein; 3 - the subclavial artery; 4 - musculus pectoralis major; 5 - musculus pectoralis minor; 6 - the musculo-cutaneous nerve; 7 - the median nerve; 8 - cutaneous internal nerves of the brachium and forearm.

The posterior branches of the three primary trunks form a secondary posterior trunk, from which the radial and axillary nerves begin. The posterior branch of the upper primary trunk

(the largest) is located in the lateral triangle of the neck, higher and more to the outside than the anterior. The other two trunks lie to the back of the other trunks and major vessels for the greatest part of their extent.

No connections are noted between the secondary posterior trunk and the two others. This confirms the position that in the proximal sections, the branches to the ventrally and dorsally located musculature are not connected. As concerns the connections between the external and internal secondary trunks, they are variously expressed and are sometimes very complex.

The presence of multiple connections usually coincides with a comparatively high beginning of the plexus. This is juxtopposed to the cases in which there is a clearly expressed subdivision into secondary trunks due to the small number of connections. These [secondary trunks] often coincide with the formation of the plexus from lower roots (K. A. Grigorovich).

In operative interventions undertaken as a result of firearms wounds in the area of the brachial plexus, it is necessary to consider the topographical details of the latter.

The exit point of the fifth cervical root from the spinal cord corresponds to the apex of the spinous process of the III cervical vertebra (sometimes 0.5 cm. higher); of the eighth root -- projecting to the apex of the V spinous process; and of the first thoracic root -- to the apex of the VI spinous process (A. Kagan). According to the data of T. V. Strukgof, the anterior roots lie below the posterior.

The brachial plexus in the lateral triangle of the neck is located in such a manner that closer to the vertebral column its trunks are farther from one another and take up a rather wide area, while in the direction of the clavicle they gradually come

closer together. In accordance with this, the upper roots (particularly the fifth cervical) are directed downward and outward, the middle ones (the seventh and eighth cervical) lie almost horizontally, and the lower ones (the first and second thoracic) are inclined upward and outward. The top four roots (the fourth, fifth, sixth and to a lesser degree the seventh cervical) are located more toward the front than the lower three (the eighth cervical, the first and especially the second thoracic).

The trunks forming the brachial plexus lie in the space between the anterior and middle scalene muscle. However, often the fifth and sixth cervical roots perforate the thickness of the anterior scalene muscle, and the fifth root is sometimes even located in front of it.

The upper primary trunk is formed somewhat below the Chassaignac's tubercle or at the level of it, and in persons with a relatively short neck -- to the outside of the lateral edge of the anterior scalene muscle and to the inside of it with a relatively long neck. To determine the point of connection of the fifth and sixth cervical roots, Erb proposed a point located 2-3 cm above the clavicle to the outside of the posterior edge of the sternocleidomastoid muscle. However, this is accurate only with a short neck. With a long neck this point usually lies somewhat higher, removed upward from the clavicle /181 by 3-4 cm (K. A. Grigorovich).

In the lateral triangle of the neck with an undamaged clavicle, not only are the fifth and sixth cervical roots and the upper primary trunk formed by them well exposed to the branching division, but also the middle primary trunk (the seventh cervical root). The lower primary root and the either cervical and first thoracic roots forming it are often hidden by the clavicle and are in a closer interrelationship with the major vessels.

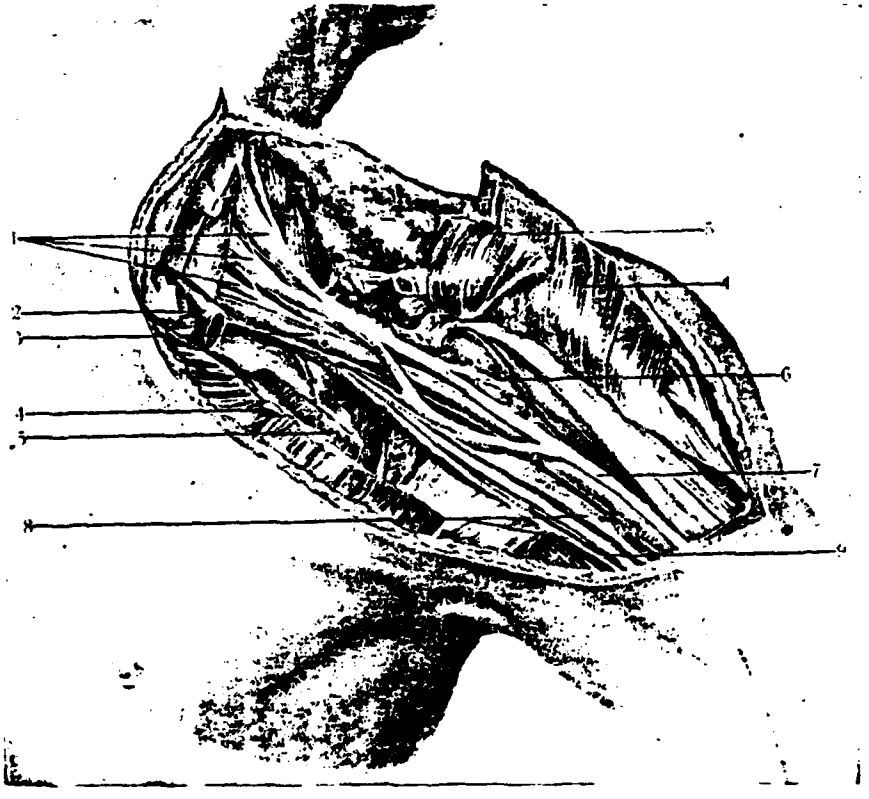

Fig. 59. The brachial plexus with caudal displacement (according to Grigorovich).

1 - trunks of the brachial plexus; 2 - subclavian vein; 3 - subclavian artery; 4 - musculus pectoralis major; 5 - musculus pectoralis minor; 6 - musculocutaneous nerve; 7 - median nerve; 8 - cutaneous internal nerves of the brachium and forearm; 9 - ulnar nerve.

The eighth cervical root is located along the upper edge of the neck of the I rib next to the transverse process of the VII cervical vertebra. The first thoracic root is directed from the lower edge of the neck of the indicated rib forward, to the outside and upward. The connecting point of the eighth cervical and the first thoracic roots in the lower primary trunk is most often covered by the anterior scalene muscle and is closer to the medial edge of the middle scalar muscle. The subclavian /182 artery at this level is located somewat lower and to the front, closer to the anterior scalene muscle. However, in other cases it covers the front of the lower primary trunk, passing somewhat above it. Aside from the subclavian artery, in close proximity with the brachial plexus are: the superficial cervical and transverse cervical artery, the transverse scapular artery, the thoracicoacromial artery, as well as their accompanying veins.

The superficial cervical artery, located almost perpendicular to the trunks of the plexus, usually intersects the upper primary trunk from the front. However, with a lower placement it may also lie in front of the middle trunk. Lower these trunks are intersected by the transverse scapular artery together with its accompanying rather large vein. These vessels always lie behind the clavicle and the subclavian muscle and after divergence of the latter are found transversely located on the anterior surface of the plexus trunks (A. S. Lur'ye). The transverse cervical artery is noted somewhat higher than the former and either adjoins the brachial plexus in the front, or passes between its trunks. The thoracoacromial artery often adjoins the internal edge of the external secondary trunk.

The veins located in this segment are of particular interest, since the hematomas which are formed as a result of wounds with injuries to the plexus or its components arise most often as

a consequence of injury to the veins rather than to the arteries. Aside from the veins which accompany the above-mentioned arteries, additional veins are usually observed, which may be in close topographical contact with the trunks of the brachial plexus. There is a particularly great number of such veins after injury to this area, when they reach a sufficiently large caliber (venous lakes). It is also necessary to keep in mind the fact that the external jugular vein before merging into the subclavian lies a short distance from the lower primary trunk. Such close mutual placement of the brachial plexus and the vessels is the reason for their combined injury with wounds to the lateral triangle of the neck. According to the data for the development of illness histories, such injuries occupy third place and are equal to 7.9% of the total number of injuries to the neuro-vascular fascicle.

The topographo-anatomical interrelations on the left side are complicated by the presence of the thoracic lymphatic duct, which upon exit to the neck is located in front of the lower primary trunk and the nerves which form it.

According to the materials of A. S. Lur'ye, the differences in the topography of the brachial plexus often coincide with the form of the given region. Thus, for example, in persons with a wide upper thoracic aperture and a relatively short neck, the anterior scalar muscle is wider and covers the primary trunks of the plexus to a greater extent. The easily accessible area of the plexus between the scalene muscles and the clavicle is in this case relatively smaller. In persons with a narrow upper thoracic aperture and a long neck, the fifth and sixth cervical root merge outside the interscalar space, and the section of the plexus accessible without dissection of the scalene muscles (in the external cervical triangle) is relatively greater.

The skeletotopy of the brachial plexus is interesting in respect to the clavicle. The upper primary trunk is divided into an anterior and a posterior branch always above the clavicle, removed upward in individual cases by up to 4 cm. The point of formation of the secondary lateral trunk is covered by the clavicle, and sometimes it is found behind its upper edge and sometimes under the lower edge. Similar fluctuations are also /183 noted among the other trunks of the plexus (fig. 60). In the area covered by the clavicle they are located close to each other and project somewhat laterally of the middle of the clavicle.

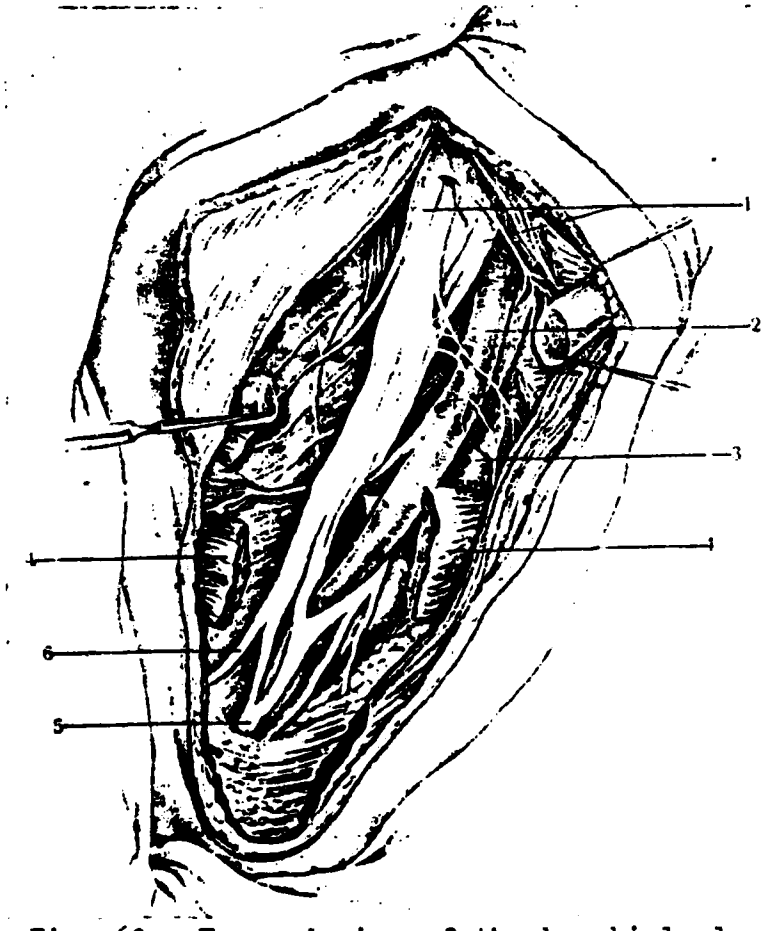


Fig. 60. Exposed view of the brachial plexus (according to Vishnevskiy).

1 - brachial plexus; 2 - subclavian artery; 3 - subclavian vein; 4 - musculus pectoralis minor; 5 - median nerve; 6 - musculo-cutaneous nerve.

The formation of the secondary trunks of the brachial plexus takes place within the margins of the claviculo-thoracic triangle (K. A. Grigorovich, A. S. Lur'ye). The subclavian artery here lies medially from the nerves. Most superficially located is the secondary lateral trunk, which is fixed by connective tissue fascicles to the fascia of the subclavian muscle. The secondary medial trunk is found more to the inside and deeper, while the posterior lies deeper still and is next to the I rib. In the /184 thoracic triangle the trunks of the brachial plexus are located around the artery in such a way that one is found to the outside of it, another -- medially, and a third -- to the rear. Often the nerves of the upper extremity, which begin from the secondary medial trunk, are divided high, already in the area where it is covered by the artery. In these cases it is not the secondary trunk which lies medially from the artery, but rather the ulnar nerve and the internal cutaneous nerves of the brachium and the forearm.

The topography of the neurovascular fascicle in the armpit changes depending on the position of the upper extremity. When the arm is lowered it adjoins the lateral surface of the first three ribs and two intercostal spaces covered by the upper denticles of the anterior denticulated muscle. With the arm abducted to a horizontal level and higher, the neurovascular fascicle remains in contact only with the upper denticle of the indicated muscle, which covers the I rib. This fact has particular significance, since operative intervention on the lower areas of the brachial plexus is done with an abducted upper extremity.

Short and long branches of the brachial plexus are distinguished. The first in turn form an anterior group (the subclavian nerve, the anterior thoracic nerves) and the posterior group (the suprascapular nerve, the dorsal scapular nerve, the long thoracic nerve, and the subscapular and axillary nerves).

The short branches are quite variable in relation to their origin from the definite cerebrospinal nerves. Great variations are also observed in regard to the number of muscles supplied by these nerves. For example, the subclavian nerve with the cranial form of plexus separated off the fifth cervical root proximally of the latter's connection with the sixth root. In such cases it is formed primarily by the fascicle of the fifth cervical root. However, its composition also includes fibers from the fourth root. In other cases the subclavian nerve begins relatively low in regard to the upper primary trunk or from its anterior branch and its composition includes fascicles of the fifth and sixth cervical root. This is observed most often with the caudal form of the plexus. In some cases the nerve begins with several fascicles, and sometimes the trunk remains doubled along its entire extent from the plexus to the subclavian muscle.

The subclavian nerve is always located more or less vertically near the outside margin of the anterior scalene muscle. With a high level of formation it lies very close to the muscle and even enters onto its anterior surface. With a low level the nerve is removed from the external edge of the indicated muscle in a lateral direction.

The connections of the subclavian nerve with neighboring nerves are numerous and varied. It comprises a complex with the diaphragmal nerve, since it often contains fascicles of the latter (K. A. Grigorovich).

The long branches of the brachial plexus form three main comples: the musculo-cutaneous -- with the median, the median -- with the ulnar and the radial -- with the axillary.

The musculo-cutaneous nerve separates off the secondary external trunk of the brachial plexus at various intervals. Usually it is formulated within the margins of the axillary fossa,

considerably more rarely -- on the boundary of the upper and middle third of the brachium. Sometimes the trunk of the musculo-cutaneous nerve is absent, and then the muscles of the flexor surface of the brachium, as well as the external surface of the forearm are supplied by branches of the median nerve (fig. 61). In these cases, injury to the latter in the upper sections of the brachium may present considerable difficulties for diagnosis and during operative intervention, since they are accompanied /185 by a loss of function in the coracobrachialis, biceps and brachial muscles with sensitivity disruptions characteristic for injury of the musculo-cutaneous nerve.

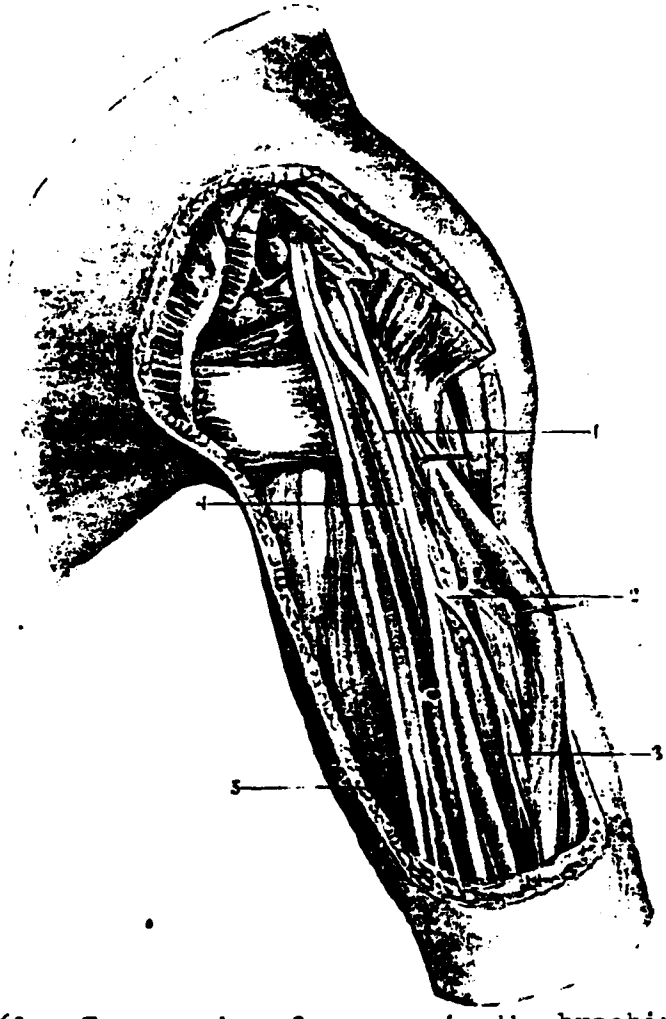


Fig. 61. Topography of nerves in the brachium with the absence of the musculo-cutaneous nerve.

Fig. 61.

1 - median nerve; 2 - branch innervating the coracobrachialis, biceps and brachial muscles; 3 - external cutaneous nerve of the forearm; 4 - brachial artery; 5 - ulnar nerve.

The thickness of the musculo-cutaneous nerve (the diameter of its cross-section), according to the data of N. A. Iozefovic, varies within from 0.2 to 0.6 cm and is found depending on the degree of expression of the external root of the median nerve. With the presence of a thin root, the trunk of the musculo-cutaneous nerve reaches a considerable thickness (fig. 62). /186 With a voluminous external rood of the median nerve, inverse relations are observed. The length of the trunk of the musculo-cutaneous nerve before its entry into the muscle is inconstant. In most cases it is equal to 1-2 cm. Considerably less frequently the musculo-cutaneous nerve is submerged into the muscle directly at the point of its formation or reaches a length of 4-5 cm, in connection with which the level of its introduction into the muscle may also change.

There are also differences in the character of branching of the musculo-cutaneous nerve, particularly at the level of divergence and in a number of muscle branches. Thus, in some cases individual branches go from the musculo-cutaneous nerve to each head of the biceps muscle, and in other cases -- only one branch comes from the nerve, and is divided into the corresponding fascicles at the very heads.

Often there are connections on the shoulder, between the trunks of the musculo-cutaneous and median nerves. In some cases the connective branch separates from the musculo-cutaneous nerve before its entry into the musculus coracobrachialis, and in others -- after the nerve passes through the indicated muscle. The connections between these nerves may be singular or multiple. Their thickness sometimes reaches 0.5 cm.

Wounds to the median nerve (above the connection) with its complete anatomical severance may stimulate partial damage.

Much less frequently there are connections between the musculo-cutaneous and radial nerve on the shoulder. In these cases they diverge from the trunk of the musculo-cutaneous nerve at the level of its branching to the brachial muscle and, winding around the posterior surface of the biceps muscle, are connected with the radial nerve at the external surface of the brachium.

At the level of the ulnar fold or somewhat higher, the musculo-cutaneous nerve comes out from under the external edge of the biceps muscle, penetrates the fascia of the brachium and spreads into the subcutaneous fatty tissue of the forearm in the form of its terminal branch -- the external cutaneous nerve of the forearm. Behind the external superficial vein (v. cephalica), this nerve is usually divided into two main branches. The anterior,larger one, accompanies the indicated vein along the internal surface and spreads to the anterior-exterior surface of the forearm. The posterior branch winds around the vein from the outside, supplying primarily the anterior-exterior surface of the forearm. Often there are connections between the two branches which are usually located on the anterior surface of the vein and in whose innervation both participate (A. V. Tsagareyshvili). In some cases there is observed a scattered character in the structure of the external cutaneous nerve of the forearm, and then its trunk is divided into 3 or 4 branches.

The sphere of distribution of this nerve is inconstant. In approximately 1/3 of the cases, the terminal branches of the external cutaneous nerve of the forearm to not reach the level of the radiocarpal articulation, terminating at the lower sections of the forearm. Much more frequently, however, the area taken up by the nerve is wider, spreading to the dorsal

surface of the hand in the area of the I metacarpal bone and the first interosteal space, covering to a greater or lesser degree the zone of cutaneous innervation of the superficial branch of the radial nerve. This explains the fact that sensitivity disruptions with wounds to the radial nerve may be limited by hypesthesia on a small area of the back of the hand in the area of the first interosteal space. This was reflected in the materials for the development of illness histories, according to which wounds to the radial nerve in the area of the hand were noted in 3.0% of all wounds to the radial nerve.

Often thin trunklets separate from the anterior branch /187 of this nerve and spread in the proximal areas of the eminence of the thumb. Sometimes they spread to the central areas of the palm, supplying the skin, palmar aponeurosis and the superficial palmar arch. In individual cases they participate /188 in the innervation of certain carpal bones, particularly the multangulum and the scaphoideum (N. A. Iozefovich). Often one of the terminal branches of the external cutaneous nerve of the forearm accompanies the radial artery, penetrating together with it to the back of the hand, where it branches in the form of a thin fascicle of fibers in the area of the first interosteal space or the proximal regions of the II metacarpal bone. This might explain the pains which arise with ligation of the radial artery at the level of the distal sections of the forearm.

The connections between the musculo-cutaneous and radial nerve in the proximal sections of the extremity, as noted above, are noted extremely rarely. Contrary to this in the distal sections, particularly in the lower third of the forearm, they are almost constant. The character of the structure of connections between the external cutaneous nerve of the forearm and the superficial branch of the radial nerve is inconstant. They may be represented in the form of straight thin branches, they may have an arched form, or they may consist of several thin

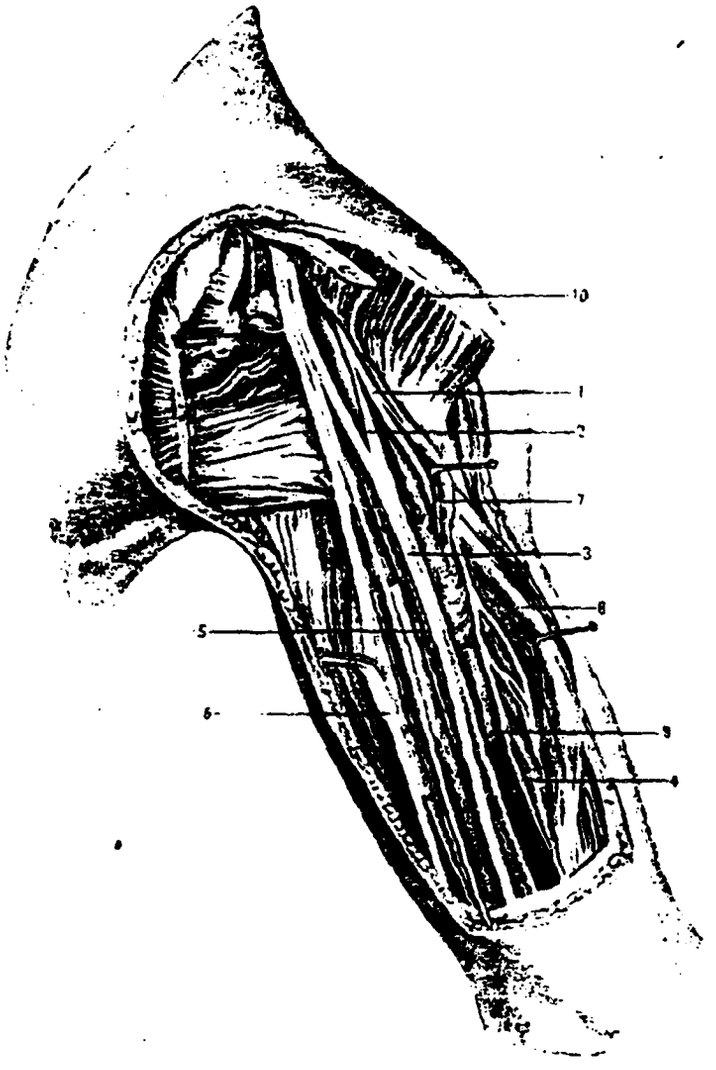


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Fig. 62. Topography of the nerves of the brachium with a well-expressed musculo-cutaneous nerve.

1 - musculo-cutaneous nerve; 2 - external root of the median nerve; 3 - median nerve; 4 - external cutaneous nerve of the forearm; 5 - brachial artery; 6 - ulnar nerve; 7 - musculus coracobrachialis; 8 - biceps muscle; 9 - brachial muscle; 10 - musculus pectoralis major.

fascicles which form complex interweavings (fig. 63). With /188
the presence of these connections, the sphere of the external cutaneous nerve of the forearm may be even more extensive and may spread to the dorsal surface of the thumb and even the index finger (fig. 64). Connections between the external cutaneous nerve of the forearm and other cutaneous nerves are observed much less frequently: the cutaneous dorsal nerve of the forearm, the internal cutaneous and cutaneous palmar branch of the median nerve.

The median nerve is formed at various levels, In individual cases the connection of its lateral and medial roots is observed high in the axillary fossa (fig. 65), and in other cases -- at the level of the middle third of the brachium and even lower (fig. 66). In this case, a wound to the brachium may be accompanied by injury to only one of the roots.

The thickness of the internal root of the median nerve varies comparatively within small limits. The most inconstant in this respect is its external root. As indicated above, the thickness of the latter is in a dependence on the degree of expression of the trunk of the musculo-cutaneous nerve, as well as the presence or absence of connections between them. This root is thickest in the absence of a musculo-cutaneous nerve trunk.

In some cases there is observed a splitting of the external root of the median nerve into two or three portions, as well as the presence of thin connective branches between its roots. These connective branches take part in the innervation of the axillary vessels (fig. 66).

The roots of the median nerve meet at a sharp angle and encompass the axillary artery on two sides. Merging, they form a nerve trunk, which is usually located laterally from the artery.

Fig. 63. Connections between the external cutaneous nerve of the forearm and the radial nerve on the hand.

1 - external cutaneous nerve of the forearm;
2 - superficial branch of the radial nerve;
3 - dorsal branch of the ulnar nerve.

Fig. 64. Deatils of the connections between the external cutaneous nerve of the forearm and the radial nerve after fibration (scheme).

1 - external cutaneous nerve of the forearm;
2 - superficial branch of the radial nerve.

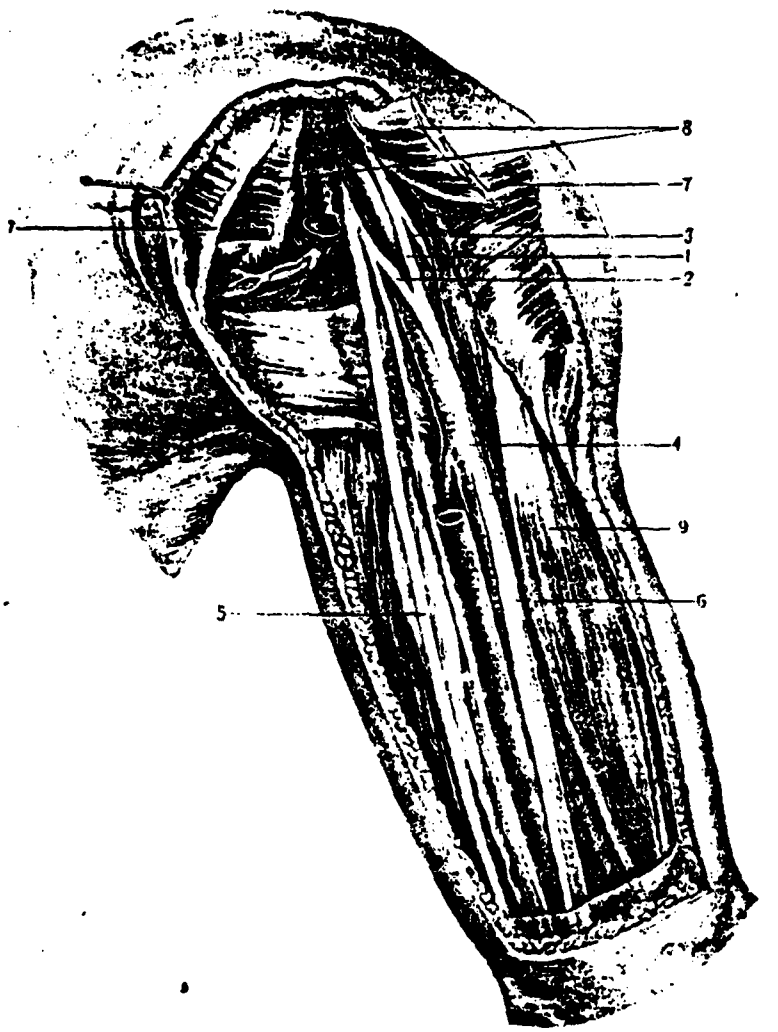


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Fig. 65. High position of the "fork" of the median nerve.

1 - external root of the median nerve; 2 - internal root; 3 - musculo-cutaneous nerve; 4 - median nerve; 5 - ulnar nerve; 6 - brachial artery; 7 - musculus pectoralis major; 8 - musculus pectoralis minor; 9 - biceps muscle.

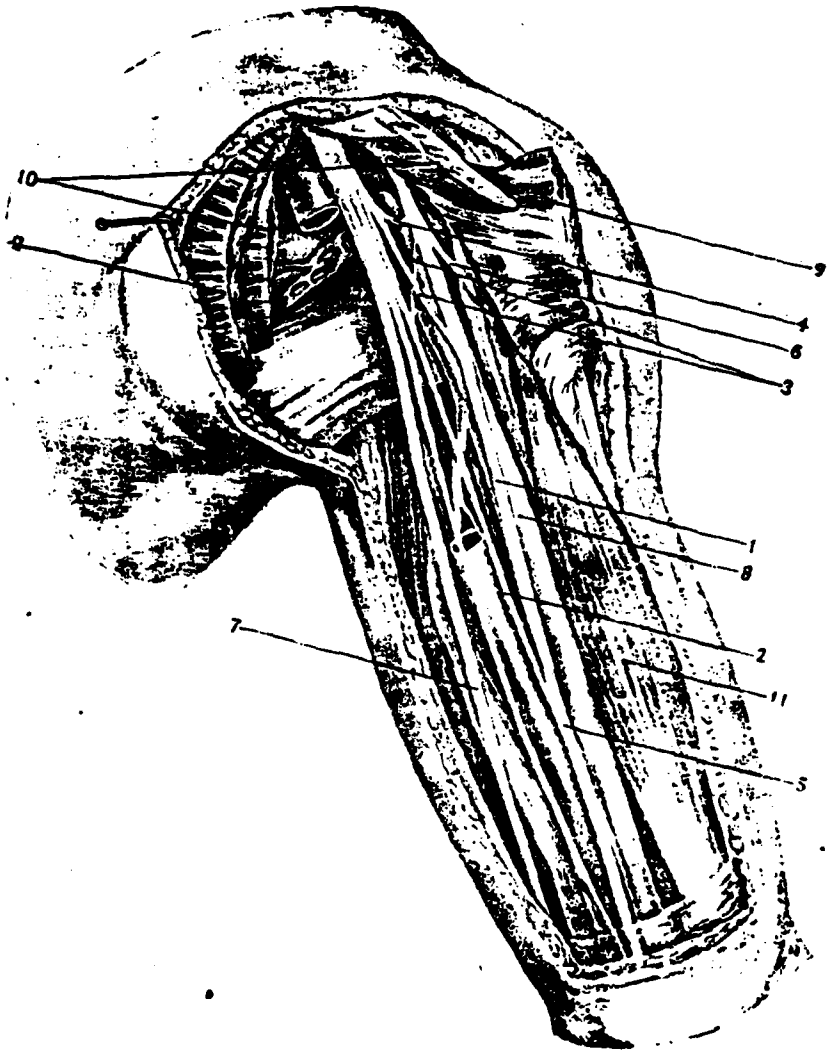


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Fig. 66. Low position of the "fork" of the median nerve.

1 - external root of the median nerve; 2 - internal root; 3 - connections between roots; 4 - small branch to the axillary artery; 5 - median nerve; 6 - musculo-cutaneous nerve; 7 - ulnar nerve; 8 - brachial artery; 9 - musculus pectoralis major; 10 - musculus pectoralis minor; 11 - biceps muscle.

osteal nerve. Diverging in the central third of the forearm from the median nerve is a fascicle of thin branches to the external belly of the superficial flexor of the index finger. Separating in the lower third from the external surface of this same nerve is the cutaneous palmar branch. Sometimes it begins higher (at the level of the central or upper third of the forearm).

Observed much more rarely is a dispersed character in the structure of the median nerve. In these cases, the greatest part of the indicated branches diverge from it approximately at the same level, within the limits of the cubital fossa. In these cases there are often observed additional palmar branches of the median nerve, diverging from its trunk at a high level (fig. 67). In these cases, disruption of sensitivity in the proximal regions of the palm with injuries to the median nerve at the forearm may be absent.

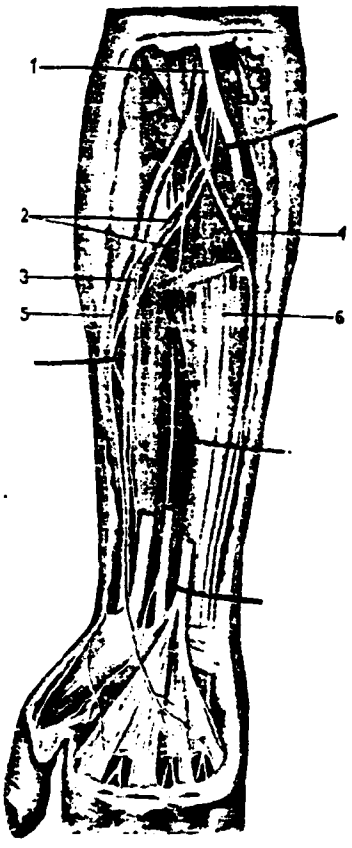
Sometimes there are connections between the cutaneous palmar branch of the median nerve and the external cutaneous nerve of the forearm or the superficial branch of the radial nerve. The sphere of distribution of the indicated branch varies within comparatively small limits. Usually it extends to the proximal regions of the palm, and sometimes reaches the middle transverse fold. With the presence of a connection with the external cutaneous nerve of the forearm, the overall zone of their branching is more extensive, reaching the level of the heads of the metacarpal bones.

The connections between the median and the ulnar nerve deserve particular mention. Usually they are localized within the limits of the upper third of the forearm (fig. 68) and may be singular or multiple, straight or arched, simple or complex. The indicated connections are located under the vascular fascicle, between the superficial and deep layer of the flexional surface muscles of the forearm.

Among the other specifics in the structure of the median nerve we should mention the longitudinal splitting of its trunk for an extent of several centimeters. Passing between both portions of the nerve are well expressed vessels (a. and v. medianae). Such splitting is most often observed in the upper sections of the forearm, which must be considered during operative intervention in the given area.

The division of the median nerve into terminal branches /193 usually takes place within the limits of the lower sections of the carpal canal. However, in some cases it is manifested near the lower edge of the transverse ligament of the wrist (Fig. 69) or at the edge of the middle and lower forearm (Figure 70) .

With a low level of division, the median nerve splits into three common palmar digital nerves, and with a higher division -- it first splits into a lateral and a medial branch, which upon leaving the carpal canal branch into the common palmar digital nerves. The latter are located along the first, second and third interosteal spaces under the palmar aponeurosis and the superficial palmar arch. Each of them supplies the corresponding sections of the aponeurosis and skin, gives off vascular branches to their accompanying arteries and to the superficial palmar /194 arch, and also innervates the nearby sections of the digital flexor tendons. Aside from this, from the I common palmar digital nerve separates a branch to the muscles of the thumb eminence. The first, second and sometimes also the third vermicular muscles are supplied by the corresponding digital nerves. Often these nerves split and then the arteries of the same tame pass through the formed loops. There are often connections between the I common palmar digital nerve and the deep branch of the ulnar nerve.



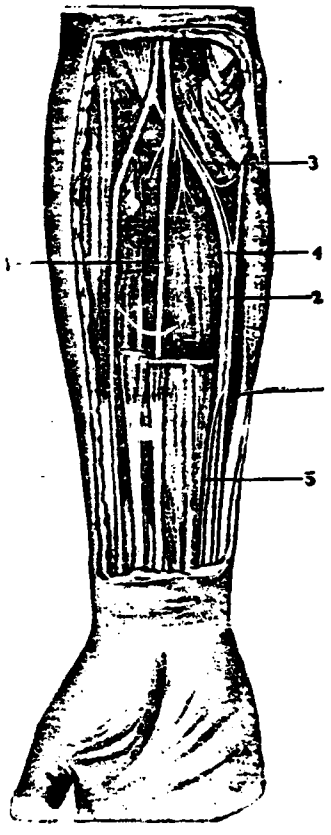
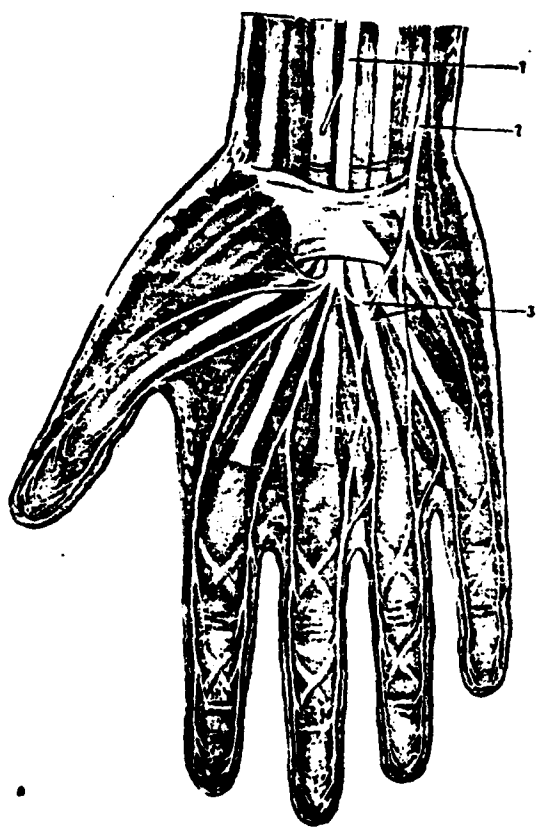




Figure 67

Figure 68

Figure 67. High departure of the metacarpal branch of the median nerve by several trunks. 1 - middle nerve; 2 - metacarpal branches; 3 - radial artery; 4 - ulnar artery; 5 - musculus brachioradialis; 6 - flexor digitorum superficialis.

Figure 68. Connections between the median and ulnar nerve in the upper third of the forearm. 1 - median nerve; 2 - ulnar nerve; 3 - connections between nerves; 4 - ulnar artery; 5 - skin metacarpol branch of the ulnar nerve.




/194

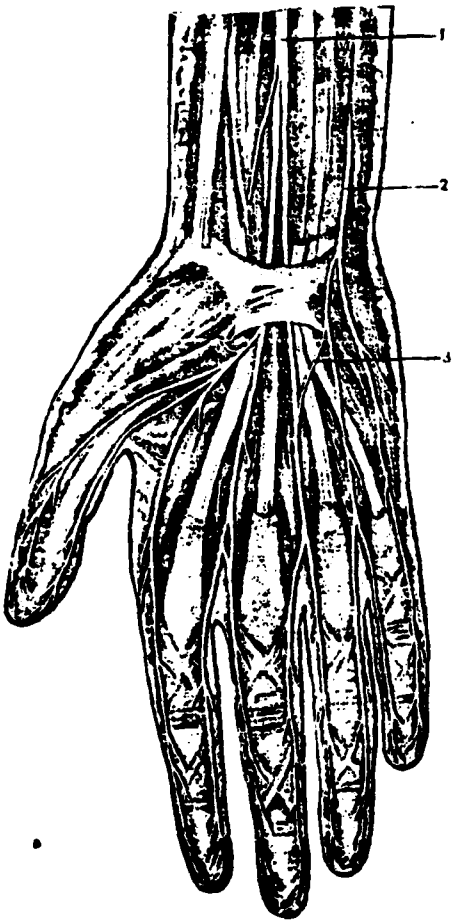
Fig. 69. Low division of the median nerve and the superficial nerves of the palm.

1 - median nerve; 2 - superficial branch of the ulnar nerve; 3 - connections between the median ulnar nerves.

In the distal sections of the hand the common palmar digital nerves diverge into 7 branches. The latter are located along the radial and ulnar edge of the palmar surface of the I, II and III digits and the radial edge of the IV finger. In the area of the terminal phalanx a small fascicle of fibers passes through a special osteo-fibrose canal to the back of the finger and branches in the subungual space. The terminal nerve branches supply the corresponding areas of the skin, their accompanying vessels, digital flexor tendons, articulatory bursae and bones. Diverging off of the proper palmar nerves of the three middle /195 fingers at the level of the metacarpophalangeal articulations (or within the limits of the primary phalanges) are branches expressed to a varying degree and spreading into the skin of the dorsal surface of the distal half of the I phalanx, the skin and the periosteum of the II phalanx, and the proximal half of the III phalanx. Aside from this, individual branches penetrate into the joint between the I and II phalanges. Approximately on the center of the II phalanx there diverges from these branches another, less constant branch, which supplies the skin of the distal half of the II phalanx and the articulation between the II and III phalanges.

The terminal branchings of the proper palmar digital /196 nerves cover each other in all the sections of the fingers. Constant connections are observed between the palmar and dorsal digital nerves.

The ulnar nerve begins from the secondary medial trunk of the brachial plexus. Sometimes it has a so-called "external foot", i.e., fascicles from the secondary lateral trunk. The level of formation of the described nerve varies within insignificant limits. According to K. A. Grigorovich, it fluctuates from the superior-medial edge of the musculus pectoralis minor to the superior edge of the musculus latissimus dorsi. According to V. F. Zabrodskaya, the beginning of the ulnar nerve is found




/195

Fig. 70. High division of the median nerve and the superficial nerves of the palm.

1 - median nerve; 2 - superficial branch of the ulnar nerve; 3 - connection between the median and ulnar nerve.

by a dense connective tissue casing which is closely connected with the epineurium as well as with the periosteum. As a result, firearms fractures are often accompanied by injury to the ulnar nerve, which confirms the materials from the development of illness histories. According to these data, combined injuries to the ulnar nerve and the bones of the forearm, primarily in the upper third of the forearm and in the elbow region, occupy first place among analogous wounds to nerves of the upper extremity and comprise 43.0% of all injuries to the ulnar nerve. Cases of nerve "dislocations" may also be observed with breaks in the medial condyle.

Further the ulnar nerve passes between the two heads of the ulnar flexor of the hand and lies along the external edge of the latter, forward of the deep digital flexor. The tendinous extension at the origin of the ulnar flexor of the hand firmly fixes the nerve to the coronoid process of the ulna. Therefore, in isolating the nerve for purposes of suture application, it becomes necessary to dissect this aponeurotic plate. In the upper half of the forearm the nerve is covered by the internal edge of the superficial digital flexor. In the lower half it is located between the ulnar flexor of the hand and the superficial flexor of the fingers, in the fascial sheath of the latter. At the boundary of the upper and middle third of the forearm, /197 the ulnar artery and vein approach the nerve, and further lie to the outside of it.

The ulnar nerve does not branch on the brachium. At the level of the ulnar articulation, several short branchlets separate off of it to the internal surface of the joint bursa, and within the limits of the upper third of the forearm -- branches to the ulnar flexor of the hand and to the ulnar portion of the deep flexor of the fingers. In individual cases it is possible to note at this level the presence of thin fascicles to the medial head of the superficial digital flexor.

At the level where the vascular fascicle approaches the ulnar nerve, the cutaneous palmar branch (r. cutaneus palmaris n. ulnaris) diverges from the latter, and accompanies the ulnar artery and veins to their branching on the hand, as well as participating in their innervation (Ye. M. Margorin).

With the presence of a connection between the ulnar and median nerve in the upper third of the forearm, the cutaneous palmar branch diverges at a lower level -- in the middle or lower third of the forearm (fig. 74). In some cases it divides at the point of its formation into two branches, one of which innervates the upper sections of the vascular fascicle, and the other -- accompanies it in a distal direction.

In the middle third of the forearm, a connective branch usually comes off the cutaneous palmar branch to the external cutaneous nerve of the forearm, and within the limits of the lower third -- a thin branch penetrating the fascia and spreading in the skin of the palmar surface of the radiocarpal articulation and the ulnar edge of the hand. The area taken up by the terminal branches is inconstant. In some cases it is limited to a small area of skin in the proximal sections of the eminence of the V finger, and in others -- it takes up a considerable section on the ulnar edge of the hand and the palmar surface, partially covering the zone of innervation of the cutaneous palmar branch of the median nerve. At the boundary of the middle and lower third of the forearm or somewhat below it, the ulnar nerve separates into palmar and dorsal branches of the hand.

The palmar branch of the hand goes on as a continuation of the main trunk between the ulnar flexor of the hand and the superficial flexor of the fingers. Then it bends around the radial edge of the pisiform bone and separates into a superficial and deep branch in front of the transverse ligament of the wrist.

Its level of division varies within insignificant limits and usually fluctuates within the boundaries of the placement of this bone (N. A. Iozefovich).

The superficial branch of the ulnar nerve near the point of its formation is divided into the internal proper palmar nerve of the V digit, located on the ulnar edge of the palmar surface of the hand and the V finger, and the IV common palmar digital nerve, which passes along the fourth interosteal space under the palmar aponeurosis and, analogous to the other common palmar digital nerves, separates into two proper digital nerves which supply the mutually facing surfaces of the IV and V digits.

There are connections between the superficial branch of the ulnar nerve and the median nerve on the hand (fig. 69). Usually they are represented in the form of a fascicle of fibers of varying thickness directed from the trunk of the superficial branch of the ulnar nerve (or from the IV common palmar digital nerve) to the III common palmar digital nerve. In individual cases these connections have the form of an arch, turned with its convex side downward, or they consist of multiple thin fascicles which weave around the superficial palmar arch. With the presence of a straight connective branch, part of the fibers from the ulnar nerve usually change over into the composition of the external proper palmar nerve of the IV digit and much more rarely -- into the composition of the internal proper palmar nerve of the III digit. With an arch-like form /198 of the connecting branch, the fibers from the ulnar nerve enter into the composition of the III common palmar digital nerve, spreading further in a proximal direction. In these cases, as well as in the presence of a connection formed by vascular branches, the ulnar nerve does not play a part in supplying the facing surfaces of the III and IV fingers. In accordance with this, the anterior-external surface of the IV digit in most cases receives dual innervation due to the fibers of the median

and ulnar nerves, and much more rarely is supplied by the median nerve alone. The anterior-interior surface of the III digit is almost always innervated only by the median nerve.

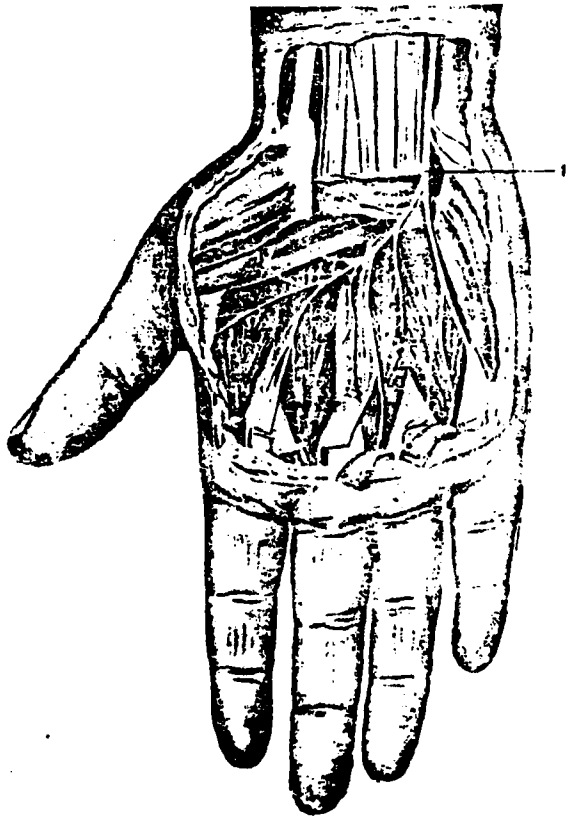
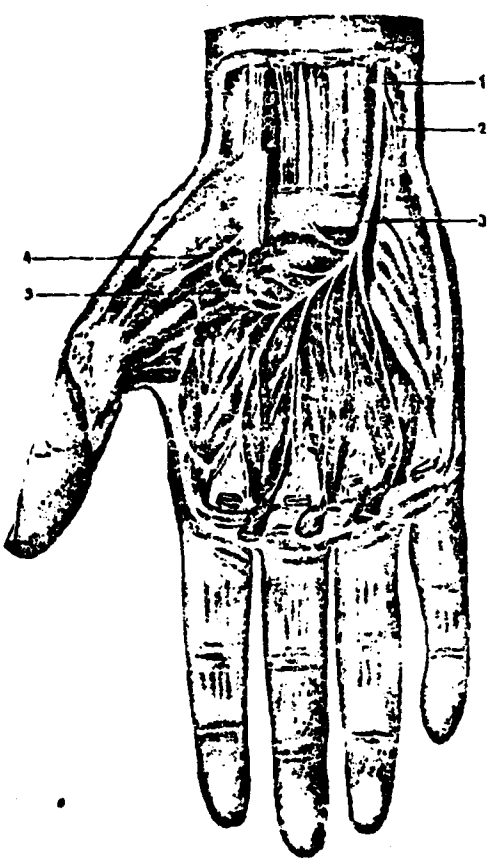



Fig. 71. Main division of the deep branch of the ulnar nerve (1).

The deep branch of the ulnar nerve separates from the palmar branch usually at the level of the pisiform bone. Passing between the point of divergence of the muscle abducting the fifth finger and the short flexor of the V finger, this deep branch penetrates the muscle contraposing the fifth finger, arches into the depth, bending around the hook of the os hamatum, and is located on the palmar surface of the interosteal muscles. In most cases (according to N. A. Iozefovich), the trunk of /199 the deep branch of the ulnar nerve is presented in the form of an arch, turned with its convex side to the periphery, from which thin branches subsequently separate, leading to the muscles and bones of the hand (fig. 71). Much more rarely there is observed a disperse character in the structure of the deep branch (fig. 72), and then it separates into individual trunklets near the point of its formation. Part of these trunklets are located on the palmar surface of the interosteal muscles, and part pass over the superficial palmar arch.

Often there are connections between the deep branch of the ulnar nerve and the terminal branchings of the median nerve. Usually these connections separate from the muscle branches which supply the deep head of the short flexor of the III finger and join with the I common palmar digital nerve, more rarely--with the internal proper palmar nerve of the I finger (fig. 72).

There is also a constant connection between the deep /200 branch of the ulnar and the superficial branch of the radial nerve. In individual cases there may be observed connections between the superficial and deep branches of the ulnar nerve. The greatest number of connections between the deep branch of the nerve and the neighboring nerves is noted with a dispersed character in the structure of the first of the indicated branches. In these cases, some of the vermicular muscles (the second or third) receive dual innervation (from the ulnar and the median nerve).




/199

Fig. 72. Dispersed division of the deep branch of the ulnar nerve.

1 - ulnar nerve; 2 - superficial branch of the ulnar nerve; 3 - deep branch of the ulnar nerve; 4 - segment of the I common palmar nerve (from the median nerve); 5 - connection between the branches of the ulnar and median nerve.

The other terminal branch of the ulnar nerve -- the dorsal /200
branch of the hand (r. dorsalis manus n. ulnaris), as we have already mentioned, diverges from its trunk within the limits of the lower sections of the forearm. At the beginning of its path it lies along the ulna, then passes under the tendon of the ulnar flexor of the hand and branches on the back of the latter. Sometimes the dorsal branch of the hand ends at the level of the head of the ulna and does not participate in supplying the hand. In these cases its sphere it replaced by the superficial branch of the radial nerve and the internal cutaneous nerve of the forearm.

In most cases, the dorsal branch of the ulnar nerve supplies the medial half of the back of the hand and 2½ fingers. Much more rarely it spreads to 3½ fingers (fig. 73) or is limited only to the internal sections of the hand and the V finger.

Between the dorsal branch of the ulnar nerve and the superficial branch of the radial nerve there may be connections which consist of tender fiber fascicles. More often, however, there is a simple crossing of these branches without significant connections between them. In individual cases there are connections between the dorsal branch of the ulnar nerve and the internal cutaneous nerve of the forearm.

The radial nerve is formed from the posterior trunk of the brachial plexus and is its largest branch, reaching a thickness of 0.7 - 0.8 cm. The level of formation of this nerve varies within insignificant limits.

In the axillary fossa the radial nerve lies in front of the subscapular muscle and tendons of the musculus teres major and the latissimus dorsi muscle, being separated from them

by an expressed layer of loose fatty tissue. To the front of it is the axillary artery, and to the inside and forward is the ulnar nerve. The subscapular artery intersects the radial nerve from the rear. Less often is passes between the ulnar and radial nerve, crossing the latter from the front. Further downward the radial nerve is located between the brachial artery and the long head of the triceps muscle of the shoulder and, penetrating between the medial and lateral heads of the latter, exits at the humero-muscular canal (canalis humeromuscularis). The length of the radial nerve from the edge of the musculus teres major to the humerus is equal to 9 - 9.5 cm (G. A. Rikhter). The humero-muscular canal, according to the data of M. G. Sirotkina, represents a fissural opening enclosed in the front by the posterior surface of the humeral diaphysis, and in the back in the upper two thirds -- by the long and external head of the triceps muscle, and in the lower third of the canal -- only by the external head which, starting from the external intermuscular septum of tendinous fibers, forms a dense aponeurotic plate which covers the nerve from the back. It is here that the nerve is most securely fixed to the humerus and therefore is easily injured with firearms inflicted fractures in this area.

The materials from the development of illness histories show that with firearms fractures of the humerus, there is very often (37.3%) injury also to the radial nerve. The /201 superior-external wall of the canal is formed by the initial portions of the lateral head of the triceps muscle and the internal brachial muscle, while the inferior-internal wall is formed by the medial head of the triceps muscle. In the canal the nerve passes together with the deep brachial artery and its accompanying veins, and before its division the artery is located above and to the back of the nerve. On the humerus, at the point of passage of the neurovascular fascicle, a spiral sulcus is often noted (sulcus radialis). The upper opening of

the canal is a fissure between the humerus, the internal and long head of the triceps muscle. Inferior to this is the opening in the external intermuscular septum, located 4-12 cm above the lateral condyle. Upon exiting the canal, the nerve together with the terminal branches of the deep brachial artery lies between the brachial and the brachio-radial muscle and exits into the anterior-external sulcus of the cubital fossa.

Fig. 73. Innervation of the dorsal surface of the hand.

1 - dorsal branch of the ulnar nerve; 2 - superficial branch of the radial nerve.

Diverging most proximally from the trunk of the radial nerve are the branches to the triceps muscle, as well as the cutaneous posterior brachial nerve. In some cases the branches to the indicated muscle diverge within the limits of the axillary /202 space, and then each of its heads is supplied from a single long trunk. In other cases, the innervation of the triceps muscle is accomplished by shorter fascicles which separate at various levels in the upper and middle third of the shoulder. In individual cases, as indicated above, the branch to the median head of the triceps muscle, which separates from the anterior surface of the trunk of the radial nerve, passes under the epineurium of the ulnar nerve for a short extent before it enters the thickness of the muscle.

At the boundary of the upper and middle third of the shoulder (and sometimes somewhat higher), the cutaneous dorsal nerve of the forearm (r. cutaneus antibrachii dorsalis) separates from the trunk of the radial nerve. The latter lies on the posterior surface of the radial nerve in the humeromuscular canal, directed downward and to the outside. At the boundary of the middle and lower third of the brachium, behind the external superficial vein, it penetrates the fascia and branches in the external segments of the area of the ulnar articulation and the posterior surface of the forearm.

The sphere of distribution of the branches of this nerve is extremely inconstant. In most cases its terminal branches end at various levels of the lower third of the forearm, participating in the innervation of the subcutaneous veins, and sometimes supplying also the distal epiphysis of the radius. In individual cases the terminal branches spread in the central areas of the carpus and even more rarely reach the middle of the carpal bones. With the presence of connections between this nerve and the superficial branch of the radial or dorsal

branch of the ulnar nerve, the sphere of distribution of the cutaneous dorsal nerve of the forearm is more extensive, reaching the primary phalanges of the II, III and IV digits.

In the lower third of the brachium, branches diverge from the trunk of the radial nerve to the brachioradial muscle and to the radial flexor of the hand. Rarely on this same level branches diverge from the medial surface of the nerve also to the brachial muscle.

At the level of the external condyle of the brachium or somewhat higher, the radial nerve is divided into a deep and a superficial branch. The first is located to the back and to the outside, and the second -- to the front and to the outside.

The deep branch of the radial nerve passes through the canalis supinatorius, giving several branches to the m. supinator. Then it spirals around the neck of the radius and crosses to the dorsal surface of the ray, where it divides into terminal branches. Sometimes this division takes place within the limits of the lower section of the canalis supinatorius.

The character of branching of the deep branch of the radial nerve is inconstant. In individual cases it immediately disintegrates into a fascicle of thin branches which supply the muscles of the extensor surface of the forearm, and in others there is observed a subsequent divergence of branches from the main trunk. Most proximally diverging in such cases are the small branches to the common digital extensor, followed by branches to the proper extensor of the fifth finger and to the radial extensor of the hand. Located somewhat deeper are the branches to the long extensor of the thumb, to the muscle abducting the thumb (long), to the short extensor of the thumb, and to the proper extensor of the index finger.

Dividing from the deep branch of the radial nerve at this same level is the dorsal interosteal nerve of the forearm, which begins sometimes independently, but more often jointly with the muscle branches. Injuries to this nerve are often accompanied by severe trophic disruptions. The described nerve is located on the dorsal surface of the interosteal septum and in the distal sections of the forearm it gives out thin branches to the periosteum of the radius and the ulna. The character /203 of its branching, as also the area of its distribution, varies within considerable margins. Usually the dorsal interosteal nerve of the forearm is divided at the level of the radiocarpal articulation (fig. 74), and sometimes somewhat higher into a different number of branches. In some cases they supply the entire dorsal surface of the radiocarpal articulation bursa, and in others -- the zone of distribution of these branches is limited to only the proximal sections.

The superficial branch of the radial nerve passes in the space between the brachioradial muscle and the radial long extensor of the hand, penetrates the fascia of the forearm by 5-9 cm proximally of the radiocarpal articulation, and splits into terminal branches. Their number, as well as their sphere of distribution, is inconstant. In most cases the superficial branch of the radial nerve is the predominant nerve in the dorsal surface of the hand, supplying from 3 to 4½ fingers, and sometimes spreading to the entire dorsal surface of the metacarpus (fig. 75). Much more rarely this branch /204 is limited to the radial half of the metacarpus and 2½ fingers. In exceptionally rare cases the zone of cutaneous innervation of the superficial branch of the radial nerve may be narrowed due to the terminal branchings of the external cutaneous nerve of the forearm.

Often it is possible to observe the spreading of the superficial branch of the radial nerve to the anterior-external and central sections of the eminence of the thumb.

Fig. 74. Dorsal interosteal nerve of the forearm (1).

/203

Fig. 75. The superficial branch of the radial nerve supplies almost the entire dorsal surface of the hand.

1 - superficial branch of the radial nerve; 2 - external cutaneous nerve of the forearm.

The sphere of distribution of the dorsal nerves on the /204
fingers is changeable. A certain constancy is observed only in the I digit, where both dorsal nerves reach its ungual bed (fig. 76). Less constant is the distribution of the dorsal nerve on the V digit (from the r. dorsalis n. ulnaris). In most cases the dorsal nerves spread here to the end of the finger. In approximately 1/3 of the cases they end at the level of the first metacarpo-phalangeal articulation. Dorsally the nerves of the II-IV fingers consist of thin fiber fascicles which usually terminate within the limits of the primary phalanges of these fingers.

Fig. 76. Innervation of the dorsal surface of the thumb.

1 - external cutaneous nerve of the forearm;
2 - superficial branch of the radial nerve.

The internal cutaneous nerve of the forearm begins from the second medial trunk of the brachial plexus, usually at the same level as the ulnar nerve, and sometimes somewhat higher. In rare cases the internal cutaneous nerve passes a short distance under the epineurium of the ulnar nerve. First it lies on the anterior-internal surface of the brachial vein,

at the center of the brachium it penetrates the fascia and divides into two branches, one of which -- the palmar -- accompanies the v. basilicae (along its external surface), branching on the ulnar side of the anterior surface of the forearm. The other branch -- the ulnar -- passes along the dorsal surface of the indicated vein in the direction toward the internal condyle of the brachium and branches in the skin at the back of the ulnar surface of the forearm.

The sphere of distribution of the terminal branches of the internal cutaneous nerve of the forearm varies within considerable limits. Often the palmar branch spreads almost throughout the entire anterior surface of the forearm, partially covering the terminal branchings of the external cutaneous nerve of the forearm, joining with it with thin branches. In other cases the internal cutaneous nerve takes up only a thin strip along the internal surface of the forearm. In most cases the terminal branches of this nerve end in the lower third of the forearm and do not participate in the innervation of the /205 hand. Much more rarely the posterior branch of the indicated nerve (r. ulnaris) spreads into the region of the ulnar edge of the dorsal surface of the radiocarpal articulation, participating in the innervation of the dorsal surface of the hand, while the volitional branch of this nerve supplies the skin in the proximal regions of the eminence of the thumb.

The internal cutaneous nerve of the forearm has connections with the branches of the cutaneous external nerve region, the cutaneous palmar branch of the ulnar nerve, the dorsal nerve of the forearm and rarely with the dorsal branch of the ulnar nerve.

## General principles of the methodology of operative access to the nerve trunks

Positive outcomes of operative treatment of the peripheral nervous systems greatly depended on the timely and properly rendered first aid, proper preliminary treatment of the wound, attentive care of the paralyzed extremity, and an operation performed at the proper time with adherance to the basic rules of its performance. A knowledge of anatomy, extreme care in handling the nerve trunk, safeguarging the epineurium against trauma, good hemostasis in the wound -- all these circumstances create the necessary conditions for regeneration. Crushed muscles, particularly after fragment wounds, which form thick scars above the nerve which press on it, small marginal necroses of the skin facilitate secondary infection of the wound and divergence of its edges. In these cases, inflammatory illness of the nerve trunk itself may arise.

The implementation of operative intervention on the peripheral nerve after firearms wounds requires good long-term anesthetic and development of a plan of access to the nerve.

Methods of anesthesia. Operations on the peripheral nerve trunks were performed during the Great Patriotic War under various types of anesthetic: ether narcosis, cerebrospinal anesthesia (for the lower extremities) and various types of local anesthesia.

Before the Great Patriotic War many surgeons believed that the use of narcosis during operations on the peripheral nerves is the most appropriate method of pain killing. There was the opinion that local anesthesis does not allow free and widespread manipulation in the wound, and does not allow detailed examination of the entire wound area and performance of the necessary operative treatment.

The practice of operative intervention on nerve trunks after firearms wounds has shown that often these operations are lengthy, and therefore general narcosis is undesirable, particularly since most of the wounded patients were subjected to repeated operative intervention.

The extensive experience of a number of surgeons using local anesthetic before the war during operations on the peripheral nervous system testifies to the fact that the very method of anesthesia has a number of additional advantages which aid the surgeon in isolating the nerve trunk and in working on it. These advantages were especially apparent in operations on firearms wounds to the nerve trunks surrounded by a large number of scars and commissures.

The long-term results of operations performed under local anesthetic studied by numerous authors show that with this method of anesthesia, subsequent nerve regeneration does not suffer in the least.

Extensive and deserved attention was given during the /206
war to the method of "close creeping infiltrate" with novocaine according to A. V. Vishnevskiy, which not only provides excellent anesthesia, but also aids the surgeon in isolating and dividing the commissures in the wound near the nerve. Stretching the scars and separating their loose commissures, the "hydraulic preparation", as A. V. Vishnevskiy called it, clearly reveals numerous pathological changes in the center of injury. We may definitely say that, for example, the neurolysis operation is made easier by one-half under conditions of "hydraulic preparation" according to Vishnevskiy. It is specifically in the so-called "edema" that the nerve contours and its branches with all their pathomorphological changes are particularly well and clearly delineated. The nerve is usually visible, as if

traced, among the other tissues. The anatomical structure of the wound area is manifested more clearly due to the unique infiltration of the novocaine solution into the surrounding tissues. Anesthesia by the Vishnevskiy method was fully accepted during the time of the Great Patriotic War. It was proven that this method has a number of advantages over other types of anesthesia. The technique of the method during the time of the Great Patriotic War was described to the minutest details. Therefore, in describing surgical treatment of firearms injuries to the trunks of the peripheral nervous system, it will be useful to present the description of this method widely used during the Great Patriotic War. An acquaintance with this method will undoubtedly also in the future have a great influence on greater improvement in the techniques of operating on the nerve trunks. The utilization of this method of anesthesia combines well with methods of broad approach to the nerve trunks. Such approaches are much harder to implement with standard local infiltration anesthesia, since such anesthesia encompasses a narrower region. Creeping infiltrate makes it possible to broadly anesthetize the musculo-fascial sheath of the extremity. /207
Anesthesia according to Vishnevskiy in nerve operations is performed by stage. Cutaneous anesthesia along the course of the future incision is performed with a solution of the following composition: sodium chloride 5.0, potassium chloride 0.075 g, distilled water 1,000 $cm^3$, novocaine 2.5 g, adrenalin solution 1 : 1,000 2 $cm^3$.

Cutaneous anesthesia is achieved by the introduction of novocaine from a two-gram syringe with the formation of a wide field of "lemon peel" (fig. 77).

After anesthesia of the skin, the subcutaneous fatty tissue is infiltrated through the undamaged skin. Anesthesia of the subcutaneous fatty tissue is done with a large syringe (5-10 gram). After this, the skin is dissected together with the subcutaneous

/206

Fig. 77. Local infiltration anesthesia according to Vishnevskiy.

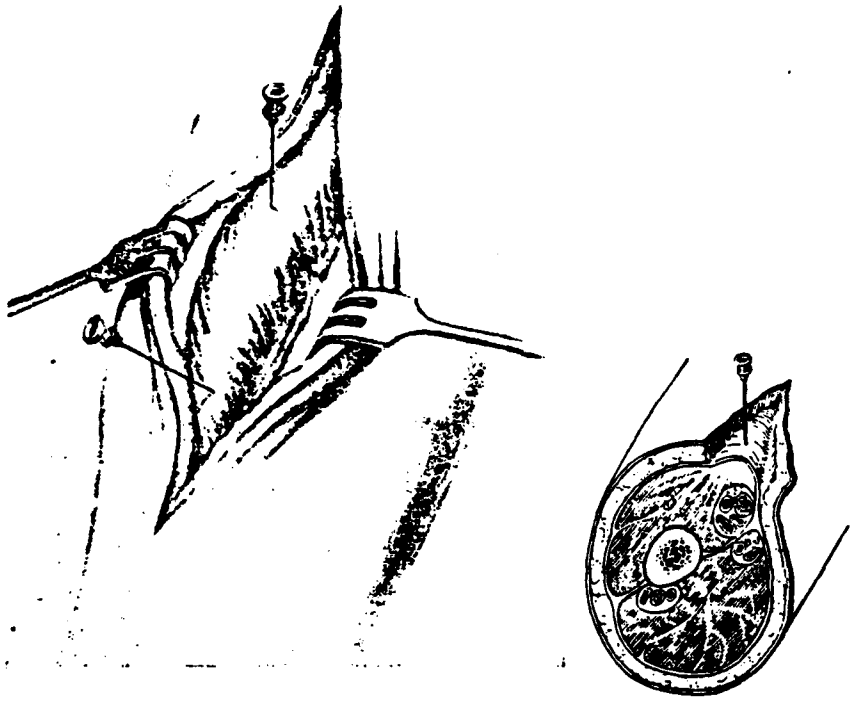


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Fig. 78. Local infiltration anesthesia. The skin and the subcutaneous fatty tissue are dissected and moved aside. Anesthesia of the fascial sheath of the anterior muscles of the brachium is performed.

fatty tissue to the appearance of the aponeurosis. The novocaine solution is "poured" to capacity into the appropriate muscle bed without opening the latter through the insulae in the aponeurosis (fig. 78). Then the skin is sectioned away from the aponeurosis.

The skin is protected with gauze pads secured with hemostatic forceps to the subcutaneous fatty tissue. Then the free end of the gauze pad is lifted back away from the wound and used to cover the hemostatic forceps so that they do not interfere with subsequent work.

The skin is pulled back with a retractor toward the outside, an additional injection is made in the lower and upper corners of the wound, and the aponeurosis opened (fig. 79). If the nerves lie in the deep muscle sheath, the anesthesia of the latter is also performed. /208

If the nerve is located near the bone, the injections are led up to the latter, for example, in approaching the radial nerve on the brachium.

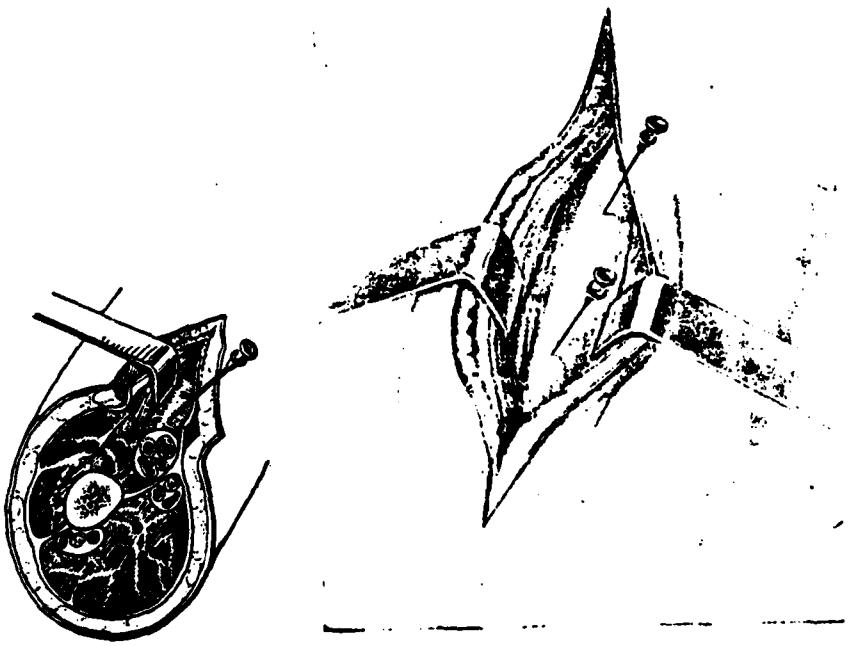

Fig. 79. Local infiltration anesthesia. The anterior fascial bed of the brachium is dissected. The biceps muscle is moved to the outside. Infiltration of the neurovascular fascicle sheath is performed.

The isolation of the nerve after retracting the muscle is begun from its central segment, moving later to the peripheral. After the nerve is freed, anesthesia is performed on its central and peripheral segment (the latter is also often sensitive) with injections under the epineurium using a very thin needle. The needle should not be injected into the thickness of the nerve itself until the character of the operation is clarified. It is necessary to know that the novocaine introduced under the epineurium spreads very rapidly throughout the abundant lymphatic fissures of the endoneural space. Therefore, in isolating the nerve it is recommended that these injections be repeated, using more concentrated novocaine solutions (1-2%).

The isolation of the nerve must be done bluntly but carefully with two mouse-tooth forceps, moving apart but not tearing the well "filled" fatty tissue of the neurovascular fascicle. The nerve is not to be taken with the forceps. In preparation, /209 only the tissue surrounding the nerve should be taken. It must be considered mandatory to isolate the central and peripheral segment of the nerve until healthy nerve tissue appears. It is usually from here that any restorative operation on the nerve is to be performed. The isolated parts of the nerve are retained by gauze strips placed under them and soaked in novocaine. Carefully pulling the gauze strips from the top and bottom, the surgeon frees the actual place of injury of the nerve trunk. Here the presence of novocaine infiltrate in the tissues surrounding the nerve considerably facilitates the process of isolation.

If it is necessary to resection the nerve and excise a neuroma, the introduction of concentrated 1-2% novocaine solution into the thickness of the actual neuroma is mandatory.

The application of local anesthesia according to the type of infiltration anesthesia after Vishnevsky should not be a "condition without which it is impossible to proceed". If local

anesthesia does not give full pain killing effect, narcosis should be used, which in no was discredits the principle of local anesthesia.

B. G. Yegorov used combined regional local anesthesia in all cases of exposure of the brachial plexus. For this he used his own modification of Kulenkampf's method. The disadvantage of this latter method is the possibility the needle injuring the subclavian vessels in the cervical pleura and the apex pulmonix. Yegorov's modification eliminates all this. Anesthesia is performed half an hour before making the incision. It consists of the following: 2% novocaine solution is used to anesthetize the point in the area of exit of the cervical plexus cutaneous nerves at the middle external edge of the sternoclaidomastoid muscle. We know that somewhat deeper and below the indicated point is the intersection of the sternocleidomastoid muscle with the anterior scalene muscle which lies under it and is covered with fascia. The point of the needle is submerged into the thickness of the anterior scalene muscle. After the needle passes through the thickness of the muscle, the patient immediately experiences characteristic paresthesia emanating from the trunks of the superior region of the brachial plexus. Introduced into this region of the brachial plexus are 40 $cm^3$ of 2% novocaine solution with addition of 4-5 drops of adrenaline solution 1 : 1,000. Then 0.25% novocaine is used to perform standard impregnation along the line of the indicated incision. In all cases, complete and very long-term anesthesia set it, which allowed the performance of the most lengthy manipulations on the brachial plexus. B. G. Yegorov notes that local anesthesia performed 30-40 minutes prior to the start of the incision always makes it possible to operate painlessly for a period of 3-4 hours.

## The methodology of operative access to nerve trunks

In approaching the nerve, speed and simplicity in locating it should not be the sole considerations. It is necessary to keep in mind the necessity of a broad access which makes it possible to clearly see the anatomical details of the operative incision as well as the consequences which may take place in the post-operative period.

The experience of the Great Patriotic War has shown that dissected cutaneous nerves may form painful neuromas, while transversely dissected muscles give rough scars, often fusing with the scars of the skin and fascia.

Moreover, the problems of restoration in operations performed/210 on nerve trunks force the surgeon to seek a method of proper approach to the nerves. The widely used projectional operative accesses to nerves often created conditions whereby the dissection of the skin, fascia and muscles was located in the same plane with the neurovascular fascicle. The thick connective tissue which developed after such an operation and which was located in the same plane as the nerve, formed immobile thick scars which hindered regeneration. This was particularly acutely expressed in those areas where the nerve was not covered by muscle. Considering the above-mentioned facts, in such cases it is not recommended to go directly to the easily palpable, acutely painful neuroma.

Observations have shown that longitudinal post-operative scars formed, for example, along the entire internal inter-muscular groove of the brachium, involved the nerve trunks so extensively into the layers of connective tissue that in successive operations it became difficult to find the nerve. Even greater difficulties arose during secondary operative interventions, when it was necessary to create favorable anatomo-physiological

conditions facilitating future regeneration of the nerve trunks. Previously, certain authors (Kokher) had proposed cutaneous incisions running perpendicular to the course of the nerve trunks. With such approaches the coincidence of skin, fascia and muscle scars formed longitudinally occurred to a lesser extent, which of course created a smaller mass of scar tissue compressing the nerve. However, these incisions for purposes of restorative operations on nerves are completely unacceptable due to the limited access to the nerve trunks. Such incisions did not make it possible either to mobilize or to suture the nerve, but only made it possible to dissect it. In firearms wounds inflicted sometimes by a large number of fragments, there was often occasion to observe injury to numerous anatomical formations of the extremities. In his time, N. I. Pirogov insisted on the necessity of making incisions in such a way that they would make it possible to operate on all the anatomical elements in the wound.

Considering the frequent injury to various tissues -- muscles, vessels, bones, it was necessary to adhere to the following basic principle in access to the nerve trunks: the surgeon first of all had to isolate the central and peripheral ends of the nerve trunk above and below the point of injury, since the isolation of nerve segments within the limits of healthy tissues always introduced clarity into the picture of the most confused anatomical structures.

The principle of incisions proposed and propagandized by G. A. Rikhter (see fig. 77, 78 and 79) makes it possible to create conditions in which the skin and fascial scars formed after the operative intervention would not be located directly above the nerve, and the point of muscle retraction in access to the nerve will not coincide with the fascial incision. This principle of access to the nerve trunks was successfully used

by numerous surgeons (T. I. Gliner, B. G. Yegorov, A. P. Yevstropov, V. I. Ivanovskiy, M. G. Taboriskiy, S. L. Firer and others).

However it is necessary to consider that any extra-projectional incision must be made in such a way that at any moment in the course of the operation it would be possible to prolong it without limitation in both directions. The operative wound must be wide and convenient for the work of the surgeon so that it would be possible to precisely and freely perform all the necessary manipulations. Small, narrow incisions during operations are more traumatic for the surrounding tissues. Cutting the muscles in nerve access is not recommended. They may only /211 be separated along the intermuscular fissures. In places where it is necessary to transversely dissect the muscles, the incision should preferably be made in the tendinous part, outside the nerve projection, and at the end of the operation the dissected muscles must be sutured.

Previously, operations on nerve trunks were customarily performed under a tourniquet. This method should be considered completely inadmissable, since most operations on nerves last a relatively long time and a tightly applied tourniquet which stops the blood flow causes pareses in the healthy nerve trunks, at the same time also disrupting conditions for future regeneration in the damaged nerve trunk. The following case is very indicative in this respect.

> In 1942, patient G—n, after healing of a firearms wound to the anterior surface of the forearm, was given a tourniquet applied to the brachium during an operation to suture the tendons of the digital flexors. The operation lasted approximately 2 hours. The next day, paresis of the median, ulnar and radial nerves was discovered, which required four months of treatment by physical methods.

Aside from this, the surgeon operating with an applied tourniquet easily overlooks the injury to numerous vessels and does not ligate them, which may lead to hemorrhaging soon after

the operation.

In operations on nerves due to firearms wounds, it is necessary to evaluate and clarify the condition of the circulatory trunks, whose injury is often combined with injury to the nerve trunks. Experience has shown that good hemostasis is difficult under conditions of cicatrically altered tissues, particularly after purulent complications. At the present time, good hemostasis may be achieved by means of using electrocoagulation. Thorough stoppage of bleeding in the operative wound reduces the percentage of unsatisfactory outcomes.

Returning to our discussion of the question of the rationality of directing the cutaneous incision, we must consider the fact that with flap incisions, injury is often inflicted to the subcutaneous nerves or their major branches. Painful neuromas may arise on the ends of the latter in the post-operative period, often serving as the reason for repeated operative intervention.

In those cases when healing took place with suppuration and with the subsequent formation of abundant scars, it was of course necessary to alter the direction of the cutaneous incisions as well as the form of their location. In principle, any cutaneous scar found within the limits of the operative access to the nerve is usually excised, regardless of its direction. It should be stressed that the mobilization of the skin flap containing the scar should be considered completely inadmissable, since necrotization is easily possible.

Tendon suture, correction of osteal deformations, intervention on vessels, and skin plasty often accompanied nerve operations.

In the presence of a wound located in a transverse direction, in the zone of nerve projection and with the necessity of its expansion, it was sufficient simply to add two longitudinal

incisions to its ends passing outside the projection of the nerve trunks and thereby to change the incision, giving it the form reminiscent of the figure 4. With an oblique wound, the same method may be used to obtain an S-shaped incision, which A. P. Yevstropov calls "vermicular". The application of these incisions is a prophylactic measure against the development of subsequent massive scars constricting the underlying nerves, vessels, and tendons into a single conglomerate.

## Methods of surgical approach to the individual nerve trunks of the upper extremity /212

### Operative approach to the brachial plexus

Firearms wounds to the brachial plexus were for the most part severe injuries. They were often combined with wounds to the vessels of the neck and the subclavian region, with fractures of the clavicle, cervicle vertebrae and their superior ribs.

Special indication should be made of combined wounds to the brachial plexus and injuries to the cervical portion of the spinal cord. The severe character of injuries to the brachial plexus affected the methods of operative intervention and the times of their application, which is evident from the materials for the development of illness histories (table 20)[1].

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[1] In this chapter, percentage relations are presented on the basis of charts of in-depth development of illness histories. The statistical data on the times of operative intervention expressed in percentages are presented in order of successively increasing values. For example, the number of operations performed in the period of up to 12 months after wounding includes all operative interventions performed at different times within the period of one year.

Table 20

Distribution of the frequency of operative interventions with injury to the brachial plexus depending on their character and times (in percentages)

| Character of operation | Time of operation | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | 54.5 | 86.4 | 95.5 | -- |
| Partial nerve resection. | 16.7 | 100.0 | -- | -- |
| Total nerve resection... | 50.0 | 100.0 | -- | -- |
| Other operative interventions..... | -- | 100.0 | -- | -- |
| Total.... | 48.6 | 86.5 | 91.9 | -- |

From table 20 it is evident that operative interventions with firearms wounds to the brachial plexus were performed in a period of up to 3 months after the wound was sustained in almost half the cases (48.6%), while in a period of from 3 to 6 months -- in 37.9%; in the period of from 6 to 12 months after injury, operations were performed only in singular cases, which comprised 5.4%. These data stress the significance of the proximity of specialized aid to the military region, which made it possible to operate on injuries to the brachial plexus at such early periods.

During the war, many surgeons used the operative approach to the brachial plexus along its projection in the supraclavian as well as the subclavian region. In those cases when it was necessary to expose the entire brachial plexus, often [surgeons] resorted to sawing through the clavicle with intersection of both pectoralmuscles. It was also considered necessary to subsequently restore (by suture) all the anatomical formations (K. A. Grigorovich, A. Yu. Sozon-Yaroshevich and others) (fig. 80, 81 and 82). With these methods, particularly in operations above the

clavicle, the sutures were applied directly to the trunks of /213
the brachial plexus. This method of operative approach facilitates the formation of a large number of scars which fuse all the cervical tissues with the brachial plexus and often require repeated operations.

Experience has shown that the most rational approach must be considered the following: the cutaneous incision is begun from the center of the external edge of the sternocleidomastoid muscle; then, curving the incision, it is brought to the clavicle, passes below it and, again curving the incision downward, it is passed above the Mohrenheim fossa; further the incision is brought downward to the axillary fossa along the internal edge of the deltoid muscle (fig. 80, 81 and 82).

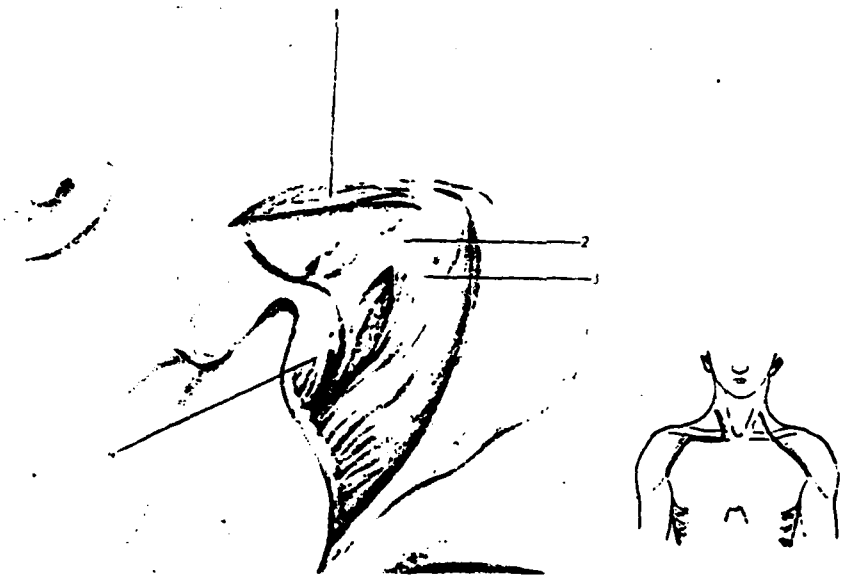

Fig. 80. Methods of operative approach to the brachial plexus: on the right -- extra-projectional method according to Rikhter; on the left -- the projection method of approach. The extra-projection approach: the skin and subcutaneous fatty tissue are dissected. The skin flaps together with the subcutaneous fatty tissue are separated to the side.

Fig. 80 (continued):

1 - sternocleidomastoid muscle; 2 - clavicle; 3 - musculus pectoralis major; 4 - deltoid muscle.

Along the dissection of skin and subcutaneous fatty tissue, the two formed angular flaps are sectioned back in the direction of their bases: the upper one to the outside and upward, and the lower -- downward and to the inside (here only the ends of the superficial cutaneous nerves of the cervical plexus spreading subcutaneously over the clavicle are damaged), and the external jugular vein is ligated. Then the second cervical fascia is opened, including the sternocleidomastoid muscle, the clavicle and the edge of the deltoid muscle are exposed (fig. 80 and 81). As the external edge of the sternocleidomastoid muscle is exposed, it is pulled back to the inside, at the same time dissecting the second and third cervical fascia. The musculus omohyoideus passes within the thickness of the third cervical fascia, and is also intersected at its tendinous intersection. The second dissection of both fasciae is performed parallel to the clavicle and the triangular flap consisting /214 of the two fasciae is sectioned to the outside. In the subclavian region the deltoid muscle is separated from the fascia, the Mohrenheim fossa is exposed and the edge of the musculus pectoralis major adjoining it is isolated (fig. 81 and 82, dotted line). Then a retractor is used to pull the sternocleidomastoid muscle toward the inside, the anterior scalene muscle is exposed at its external edge in the interscalene fissure, and the roots of the brachial plexus are found (fig. 82).

Usually it is easy to see the phrenic nerve and the point of its inferior divergence from the fifth cervical root. The upper part of the nerve diverges, as we know, from the cervical plexus (third and fourth root). All this makes it possible to obtain a complete topographical orientation.

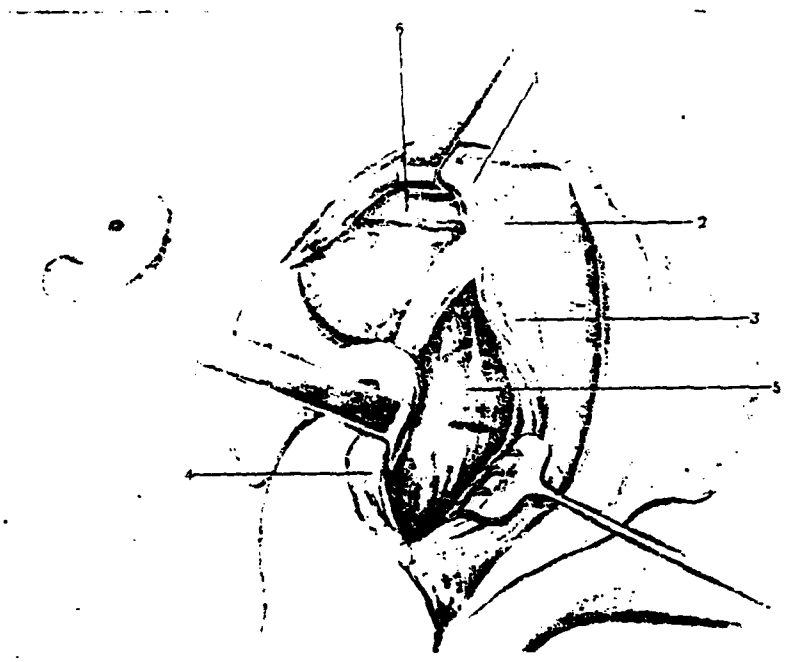


Fig. 81. Approach to the brachial plexus.

1 - sternocleidomastoid muscle; 2 - clavicle; 3 - musculus pectoralis major; 4 - deltoid muscle; 5 - musculus pectoralis minor, enclosed in deep fascia of the shoulder girdle.

In the subclavian region the isolated edge of the large pectoral muscle is retracted downward and toward the inside, and for broader access sometimes an additional incision in the large pectoral muscle (musculus pectoralis major) is made: moving back somewhat from the clavicle, the deltoid muscle is retracted toward the outside and the deep fascia of this region exposed. After dissecting the fascia above and below the small pectoral muscle together with the deep fascia, the small pectoral muscle

is intersected in its tendinous portion, and the entire fascial-muscular triangular flap is thrown back toward the inside, toward its base. When the fatty tissue is separated, the entire neuro-vascular fascicle of the subclavian region is well exposed.

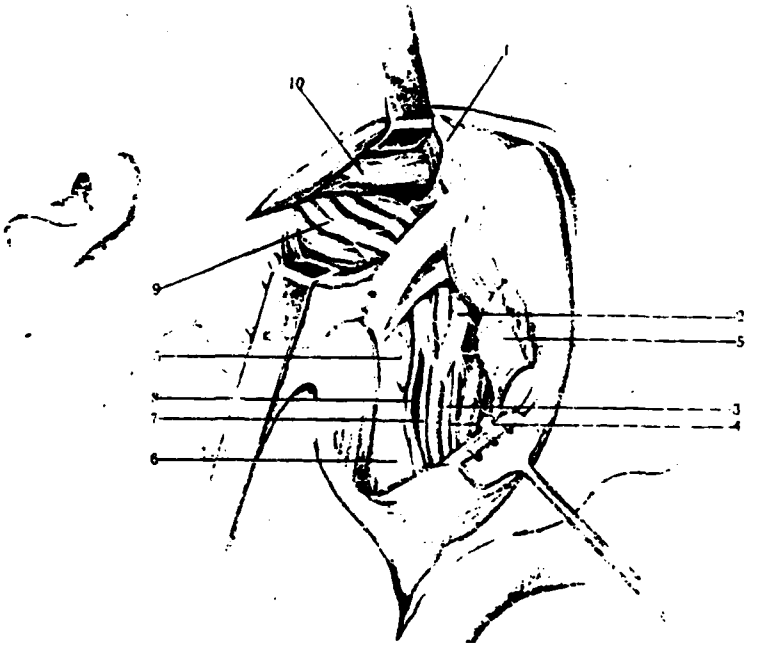

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Fig. 82. Approach to the brachial plexus.

1 - sternocleidomastoid muscle; 2 - axillary artery; 3 - ulnar nerve; 4 - internal cutaneous nerve of the forearm; 5 - intersected small pectoral muscle with nerve branches entering it; 6 - musculus coracobrachialis; 7 - median nerve; 8 - musculo-cutaneous nerve; 9 - superior roots of the brachial plexus; 10 - phrenic nerve.

With injuries to the brachial plexus at a high level, in the area of the neck, for an even more convenient access to its roots, it is recommended that the anterior scalene muscle be intersected

(sparing the phrenic nerve) and turned upwards. This makes it possible to expose the upper portion of the brachial plexus and the subclavian artery arch. It should be noted that a large number of injuries occurred to the middle section of the supraclavicular space and somewhat less -- to the brachial plexus under the clavicle.

The proposed extra-projection method makes it possible to thoroughly isolate the damaged plexus. If thick commissures are present after the injury, usually the surgeon is able to perform neurolysis from the indicated incision also in that part of the plexus which is located behind the clavicle without sawing it. Only in extreme cases, particularly with simultaneous injuries to the clavicle itself, was it impossible to isolate all the plexus without sawing the clavicle. The pressure of a bone callous on the plexus conditioned the expediency of excising the clavicle for a considerable extent (B. G. Yegorov, G. A. Rikhter).

It should be considered expedient, having finished one or another operative intervention on the brachial plexus, to strive towards restoring the anatomical relations as much as possible /216 (in the supra- and subclavian space). The only debatable question may be that of suture restoration of the intersected anterior scalene muscle, since the scar after the muscle suture shortens the muscle, thereby narrowing the interscalene space and, of course, has an unfavorable effect on the upper region of the brachial plexus. The sawed undeformed clavicle was usually sutured with silk or wire sutures. Then the entire triangular flap, consisting of the second and third cervical fascia, was put back in place and its edge sutured to the sternocleidomastoid muscle or, better still, to its fascia.

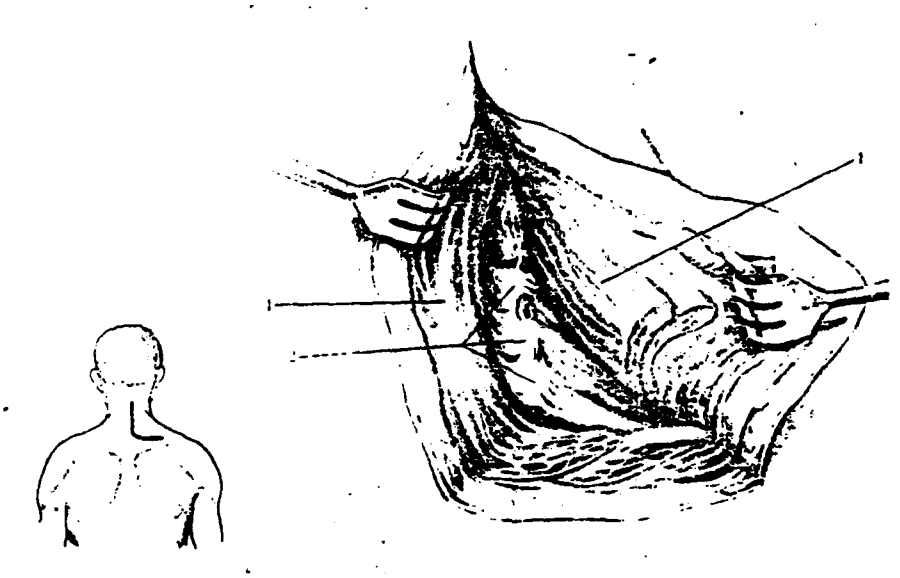


Fig. 83. Posterior access to the brachial plexus: cutaneous-muscular flap is retracted to the outside with the aid of a retractor.

1 - dorsal cervical muscles; 2 - spinous processes of the cervical vertebrae.

In the subclavian space the deep fascia is usually restored and the musculus pectoralis minor is sutured. Then thick catgut is used to suture the edge of the musculus pectoralis major with the edge of the deltoid muscle, whenever possible grasping the muscles together with their fasciae in order to avoid cutting of the applied sutures. The described operative method always gives a broad access to the brachial plexus, preserving the main anatomical elements of the region, and creates better conditions for the regeneration of the brachial plexus as well as for the healing of the tissues which have been dissected during this process.

The cutaneous incision is drawn from the rear parallel to the spinous processes of the vertebrae -- from the III cervical to the II thoracic, 2-3 cm away from them, and further curves to the inside by 8-10 cm (fig. 83).

Within the plane of this incision, all the muscles are dissected to the external areas of the arculi and transverse processes of the cervical vertebrae and the initial regions of the I and II ribs. Freeing the osteal formations from the soft tissues, the triangular flap is pulled back to the outside (fig. 83).

The transverse processes of the inferior cervical and /217
superior thoracic vertebrae are removed with bone forceps and the initial regions of the I and II ribs are resectioned. The roots are exposed from the fifth cervical to the first thoracic. The superior, middle and inferior primary fascicules are exposed along the roots (fig. 84). Incising the base of the transverse processes and the external area of the arculi, if necessary it is possible to expose the sac of the meninx (fig. 84).

The described method is applicable only for interventions on the proximal areas of the brachial plexus and only with a certain localization of the zone of injury.

The indication should be noted that the muscles separated during operative approach restore their function well after healing.

Firearms wounds with localization in the area of the shoulder girdle often damaged all the anatomical elements of the axillary fossa, the nerves and vessels. Therefore, during the operative approach all these formations are examined from a single incision.

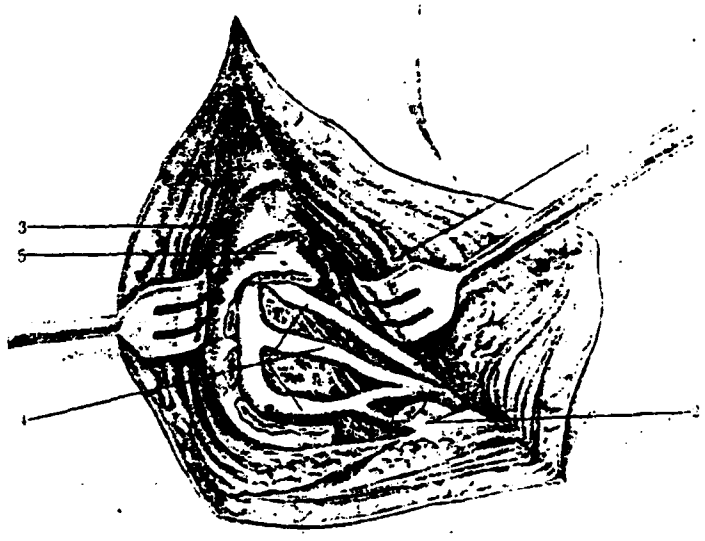



Fig. 84. Posterior approach to the brachial plexus. 1 - dorsal cervical muscles intersected and retracted to the outside; 2 - I rib; 3 - dorsal cervical muscles retracted from the midline; 4 - inferior roots of the brachial plexus; 5 - arculia of the cervical vertebrae.

For operative approach to the neurovascular fascicle in the axillary fossa, the upper extremity should be placed in the position of acute abduction. The cutaneous incision is usually performed 2-3 cm to the outside and to the front of the continuation of the internal sulcus of the brachial biceps muscle into the axillary fossa (fig. 85). The projectional incision is made in the axillary fossa along the continuation of the internal sulcus of the brachium.

The beginning of the cutaneous incision with both methods /218 goes 1.5-2 cm above the lower edge of the musculus pectoralis major. The incision is continued toward the periphery depending

on the extent of the injury, the direction of the scars, and the volume of proposed operative intervention.

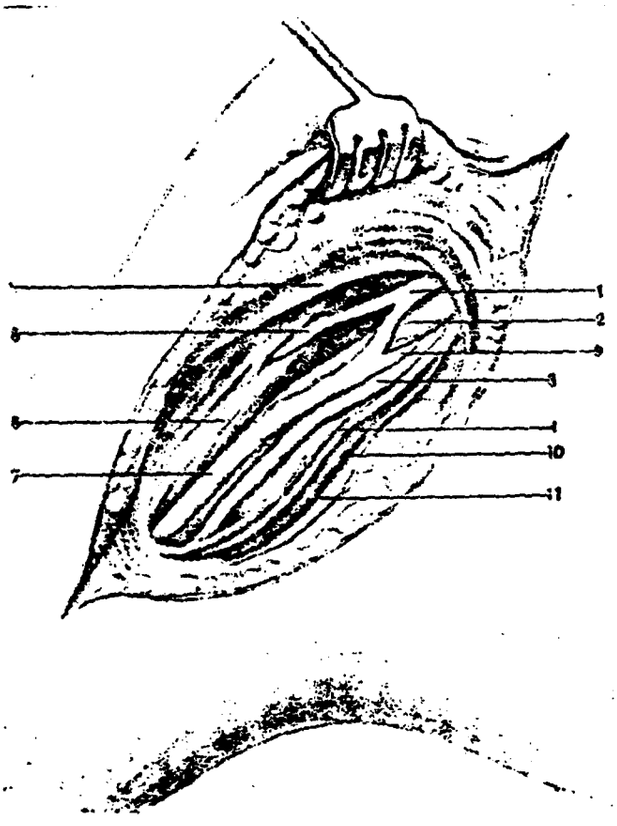



Fig. 85. Operative approach to the neurovascular fascicle in the axillary fossa.

1 - external trunk of the brachial plexus; 2 - axillary artery; 3 - ulnar nerve; 4 - internal cutaneous nerve of the forearm; 5 - musculus pectoralis major; 6 - musculus coracobrachialis; 7 - median nerve; 8 - musculo-cutaneous nerve; 9 - internal trunk of the brachial plexus; 10 - internal cutaneous nerve of the brachium; 11 - internal subcutaneous vein of the brachium.

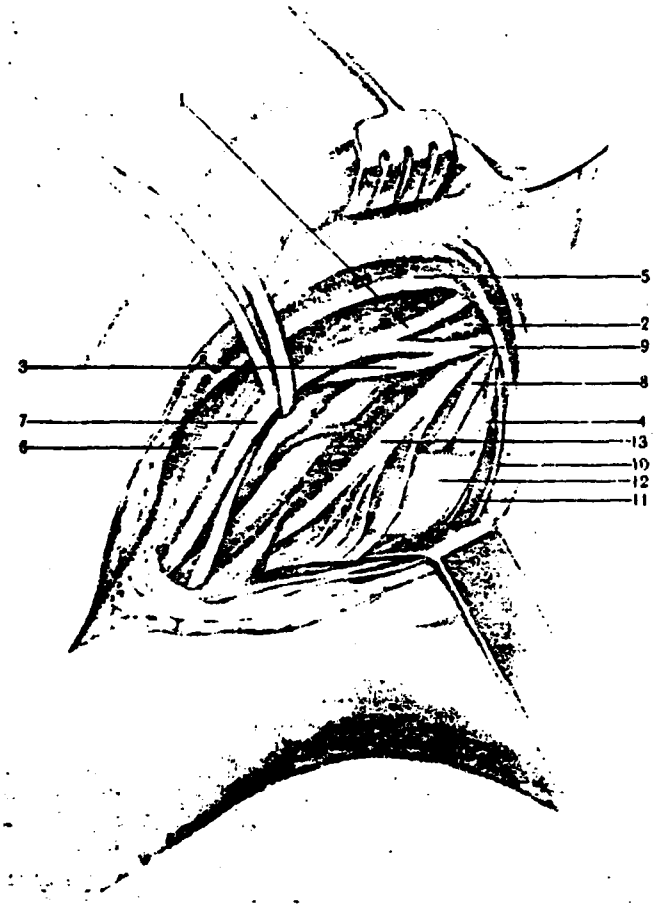
After incision, the skin is sectioned back and retracted, and then the upper region of the fascial brachial sheath is opened. The musculus coracobrachialis and the tendinous portion of the biceps muscle are found. Retracting them to the outside, the neurovascular fascicle is isolated (fig. 85).

Isolation of the musculo-cutaneous nerve. The first to be encountered is the musculo-cutaneous nerve, which lies at the upper edge of the musculus coracobrachialis and enters into it. To isolate its central section it is necessary to expose that /219 part of the nerve which passes under the biceps muscle and is located on the brachial muscle (fig. 62).

It is necessary to keep in mind the fact that the examined nerve is connected with the median nerve by a thick branch, which sometimes reaches almost half the thickness of the latter (fig. 85). This circumstance should be kept in mind in drawing diagnostic conclusions, since it sometimes leads to erroneous conclusions on the form of the injury to the median nerve. The /220 presence of this constant connection also has a great significance for the operative technique of isolating both nerves, particularly in restorative operations performed on the nerve. Often the musculo-cutaneous nerve is absent (fig. 61).

Isolation of the median nerve. The median nerve, as we know, is formed from the external and internal fascicles of the brachial plexus. In isolating the median nerve in this region it is necessary to consider its relation with the brachial artery above which the fork of the median nerve lies (fig. 85).

Isolation of the axillary nerve. The axillary nerve is formed in the depth of the axillary fossa to the inside and to the rear of the primary neurovascular fascicle, and emanates from the brachial plexus. In the presence of an isolated injury to the axillary nerve, its examination should always be begun from




/219

Fig. 86. Exposing the nerve trunks in the axillary fossa: the median and ulnar nerves are retracted to the outside to expose the radial and axillary nerve.

1 - external trunk of the brachial plexus; 2 - axillary artery; 3 - ulnar nerve; 4 - internal cutaneous nerve of the forearm; 5 - musculus pectoralis major; 6 - musculus coracobrachialis; 7 - median nerve; 8 - axillary nerve; 9 - internal trunk of the brachial plexus; 10 - internal cutaneous nerve of the forearm; 11 - internal subcutaneous vein of the brachium; 12 - tendon of the musculus teres major and latissimus dorsi.

the central nerve segment which diverges from the posterior /220
secondary trunk of the brachial plexus. The axillary nerve is easily exposed if the brachial artery is retracted to the outside together with the median and ulnar nerves. In the fissure between the broad and the subscapular muscle of the back it is impossible to miss the axillary nerve going down into the depths (Ye. M. Davydova) (fig. 86). When the indicated muscles are moved aside, the nerve is found in the space between the humerus, the musculi teres and the long head of the triceps muscle (rectangular opening).

The exposure of the axillary nerve in its peripheral segment, at the point where it curves around the surfical neck of the humerus and is covered by the deltoid muscle, is performed from a special incision traced parallel to the posterior edge of the deltoid muscle. When the fascia is opened, the edge of the deltoid muscle is found and very carefully retracted. From the opposite side of the wound, using forceps to retract the external edge of the long head of the triceps muscle, the peripheral segment of the nerve is easily found under its central portion, coming out from the depths and penetrating into the the deltoid muscle (fig. 87).

If scars are present in this area, it is expedient to incise the deltoid muscle upward parallel and 1.5 - 2 cm back from the scapula. After this, the muscle is retracted downward and, orienting along the same rectangular opening, the peripheral segment of the axillary nerve is isolated. After the operations are performed on the nerve, the integrity of the muscle is restored. Covering the sutured nerve in the area of the central segment is done by means of bringing the fibers of the teres major and the subscapular muscles together. In the peripheral segment the nerve is covered by means of suturing the deltoid muscle to the triceps and teres muscles.

The radial nerve. The initial part of the radial nerve is exposed to the back from the axillary artery. Retracting the artery backward together with the median and ulnar nerves, the radial nerve which, like the axillary, diverges from the dorsal fascicle of the brachial plexus, is isolated. In the case of firearms wounds, it is here that combined injuries of the axillary and the radial nerves are observed. In this area the radial nerve is located to the front of the tendons of the latissimus dorsi and the musculus teres major (fig. 86).

The ulnar nerve. The injured ulnar nerve may be exposed at the inside of the axillary artery. It diverges from the internal fascicle of the brachial plexus and in this area lies along the inside of the artery, between it and the vein (fig. 86).

The internal cutaneous nerve of the bradhium and forearm. The two internal cutaneous nerves -- that of the brachium and the forearm (fig. 86) are located in the recess of the subcutaneous fatty tissue at the point of connection of the fasciae forming the internal septum of the brachium. During operative /221 interventions on the inside of the brachium, it is necessary to note injuries of the indicated nerves, which may sometimes form small terminal neuromas often involved in a cutaneous scar. In these cases, part of the pain sensations observed in clinical practice must be attributed to the injuries of these cutaneous nerves of the brachium and the forearm.

It should be noted that isolated injuries of individual nerve trunks are rarely noted in the axillary fossa. Immeasurably more often there are observed combined injuries of two or several nerve trunks, muscles and vessels (K. P. Chikovani).

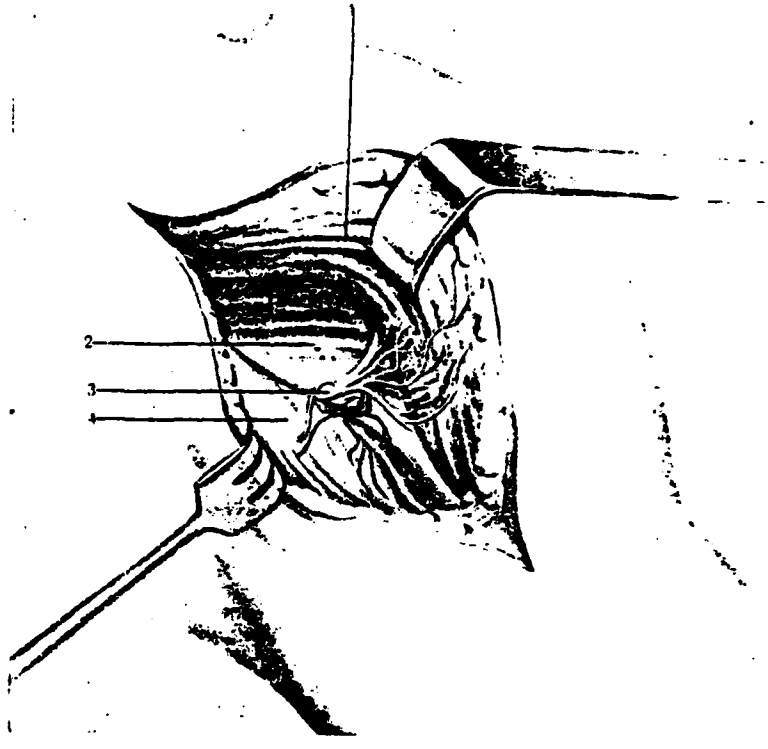



Fig. 87. Posterior approach to the axillary nerve.
1 - deltoid muscle; 2 - musculus teres minor;
3 - axillary nerve; 4 - long head of the triceps muscle.

## Operative approach to the median nerve

Firearms wounds to the median nerve were often combined in the area of the brachium with injuries to other nerve trunks and with injury to the brachial artery and vein. In the area of the forearm there were often noted combined injuries to the median nerve and the tendons of the hand and digital flexors. /222

These types of injuries to the median nerve were reflected to a certain degree on the methods of operative intervention and on the times of operation, which is evident from the materials for the development of illness histories (table 21).

Table 21

Distribution of the frequency of operative interventions with injury to the median nerve depending on their character and time (in percentages)

| Character of operation | Times of operations | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | 51.3 | 94.8 | 100.0 | -- |
| Partial nerve resection. | 44.5 | 95.5 | 100.0 | -- |
| Total nerve resection... | 52.0 | 94.0 | 100.0 | -- |
| Nerve resection without suture..... | 50.0 | 75.00 | 100.0 | -- |
| Total..... | 48.8 | 94.9 | 100.0 | — |

From table 21 it follows that complete nerve resection and neurolysis of the median nerve after firearms wounds were performed in slightly over half the cases within a time period of up to 3 months (total nerve resection -- 52.0%, neurolysis -- 51.3%). It is also characteristic that neurolysis, nerve resection without

As we know, the brachial artery is located under the median /223 nerve in the overwhelming majority of cases. Therefore, particular care is necessary in performing manipulations in this area. It should also be kept in mind that the brachial artery may lie on the median nerve, to the outside and to the inside of it (Zh. L. Kalina). Relatively frequently, the auxiliary arterial trunk lies above the median nerve, and sometimes reaches the size of the brachial artery. This is the so-called aberrating trunk. This additional trunk is observed in 9.0 - 13.0% of the cases (Zh. L. Kalina), and therefore may have a certain practical significance. Consequently, it is possible here to have injury to two arteries aside from injury to the nerve.

When the manipulations on the median nerve at the brachium have been completed, it is covered using the fibers of the coraco-brachial and biceps muscles, or the nerve is placed in the fissure between the biceps and the brachial muscles.

Access to the median nerve in the cubital fossa. In order /224 to expose the median nerve in the cubital fossa, the cutaneous incision should be made under the tendon of the biceps muscle, which is clearly contoured and palpated to the external edge of the pronator teres of the forearm. Retracting the skin backward, the fibrous Pirogov's layer is dissected and the median nerve is exposed 1-2 cm to the inside of the brachial artery. It is necessary to remember the a. cubitalis, which is located nearby. In isolating the nerve in this region, it is necessary to keep in mind the fact that this is where the motor branches begin to diverge to the muscles of the hand and finger flexors which may be found in the scars. These branches are easily mistaken for scars and accidentally severed (N. B. Chibukmakher).

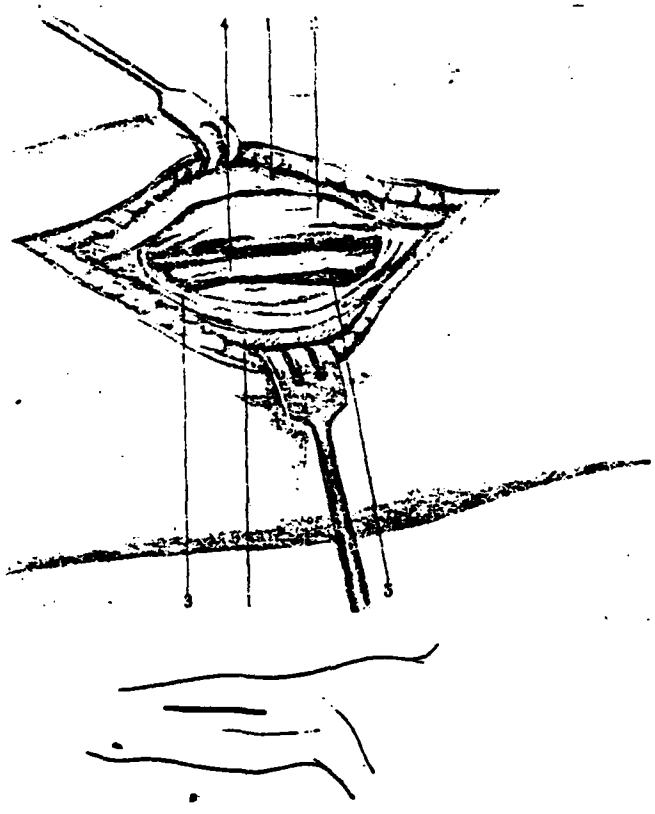


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Fig. 88. Extraprojectional access to the median nerve at the brachium. The fascia of the anterior muscle bed of the brachium has been dissected, the median nerve and the brachial artery have been exposed.

1 - the fascia of the anterior muscle bed of the brachium; 2 - interior edge of the biceps muscle of the brachium; 3 - fatty tissue of the neurovascular fascicle sheath; 4 - median nerve; 5 - brachial artery.

Operative access to the median nerve on the forearm. In order to expose the median nerve at the forearm, it should be considered rational to cut the tissue to the inside (Zh. L. Kalina) of the nerve projection. The scars of muscles and tendons which form after injury in this area often require operative intervention for their elimination. /224

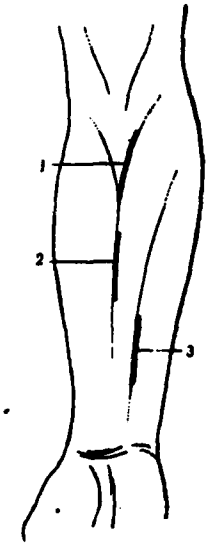


Fig. 89. Accesses to the median nerve on the forearm.

1 - access along the external edge of the pronator teres of the forearm; 2 - access along the external edge of the radial flexor of the hand; 3 - access along the internal edge of the radial flexor of the hand.

A vertical incision is made in the upper third of the forearm running along the outside edge of the pronator teres, which corresponds approximately to the continuation of the tendon of the biceps muscle (fig. 89).

As it is dissected, the skin is pulled back to the sides and the external edge of the radial flexor of the hand is isolated. Adhering to this edge, the depression between it and the internal edge of the pronator teres is found (fig. 90). Broadly separating the muscles, the median nerve is found, which gives off a significant number of locomotory branches toward the inside, which is what explains the requirement for operative approach to the nerve from the outside (fig. 89 and 91).

If it is necessary to expose the nerve more proximally, then the pronator teres should never be intersected. In these cases the nerve is exposed above and below the pronator, isolating it and its branches from the scars, and in cases requiring suture application it is pulled through the pronator or under it. If it is necessary to expose the nerve in the middle third of the forearm, then one of the cutaneous incisions shown in fig. 95 is made. Opening the fascia, the external edge of the radial flexor of the hand is found. Adhering to this edge, penetration is made into the depths to the long flexor of the thumb. Pulling apart the muscle fissure which is formed under the superficial digital flexor, the median nerve is found in the bed of the deep flexors. With injuries of the median nerve which are located still lower, the approach is done along the internal edge of the radial flexor of the hand (fig. 89).

Particular attention is given to the cutaneous incision made to expose the median nerve in the lower third of the forearm. Here it is impossible to make an incision running over the projection of the median nerve, since the latter lies between the muscle tendons and is covered only with the fascia and the skin of the forearm. After operative intervention performed using the projectional incision directly over the nerve, thick scars develop which subsequently form new scars whose liquidation even by means of subsequent operative interventions presents /225

a rather difficult problem.

The incision for access to the median nerve in the lower third of the forearm is made either to the outside or to the inside of the median nerve projection. In the presence of a transverse scar which must be excised, it is expedient to make an incision to the outside of the nerve projection on one side of the scar, and to the outside on the other (fig. 92).

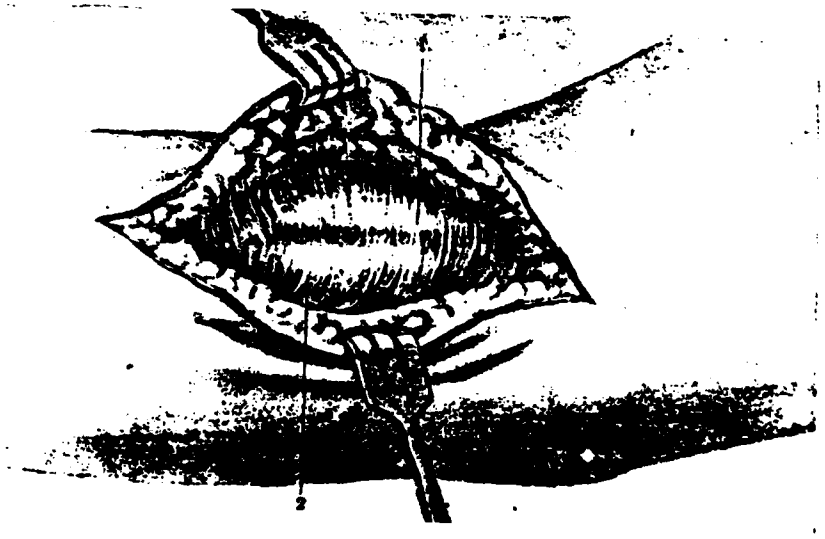

Fig. 90. Access to the median nerve in the upper third of the forearm.

1 - pronator teres of the forearm; 2 - radial flexor of the hand.

Sectioning the obtained skin flaps to the inside and to the outside of the midline, the fascial sheath of the forearm is found, which is opened above the length of the palmar muscle. The median nerve is found in the fissure between the tendon of the named muscle and the radial flexor of the hand (fig. 93).

In this area, covering the nerve from subsequent scars presents a particular difficulty, since the muscles here already change to tendons. With the extraprojectional approach, the suture of the fascia and the subcutaneous fatty layer does not coincide with the extent of the nerve. However, with the projectional approach, a thick scar is formed above the nerve which runs from the skin to the nerve.

Isolation of the median nerve in the area of the radiocarpal articulation. In isolating the median nerve near the transverse palmar ligament, it often becomes clear that the peripheral segment of the injured nerve is found under the palmar ligament. In these cases it is impossible to intersect the palmar ligament, which has a very great functional significance for digital flexion. It is possible only to slightly incise it and attempt to pull out the peripheral nerve segment. However, if this measure does not make it possible to isolate the nerve, then it is necessary to perform isolation of the median nerve on the hand. Here the median nerve is found with the aid of a cutaneous incision passing near the internal edge of the eminence of the thumb muscles. When the skin and fascia are opened, the internal edge of the external head of the short thumb flexor is found. It is necessary to isolate this edge /226 up to the transverse ligament of the forearm. In the depth and somewhat to the inside may be found the trunk of the median nerve, separating into its primary branches (fig. 89 and 90). Retracting or incising the transverse ligament, it is possible to isolate the peripheral segment of the damaged median nerve. The suture is applied at the forearm or at the hand, depending on the level of defect of the nerve trunk.

Fig. 91. Access to the median nerve in the upper third of the forearm.

1 - fascia of the bed of the anterior flexors of the forearm; 2 - pronator teres of the forearm; 3 - median nerve entering the canal of the pronator teres.

With simultaneous injury to the median and ulnar nerve, /227 the cutaneous incision in the lower third of the forearm is drawn in the center of the distance between the projections of one nerve and the other. The skin and subcutaneous fatty tissue is separated to the sides. After opening the fascial sheath of the extremity, the isolation of each of the nerves is performed in the typical place of its placement.

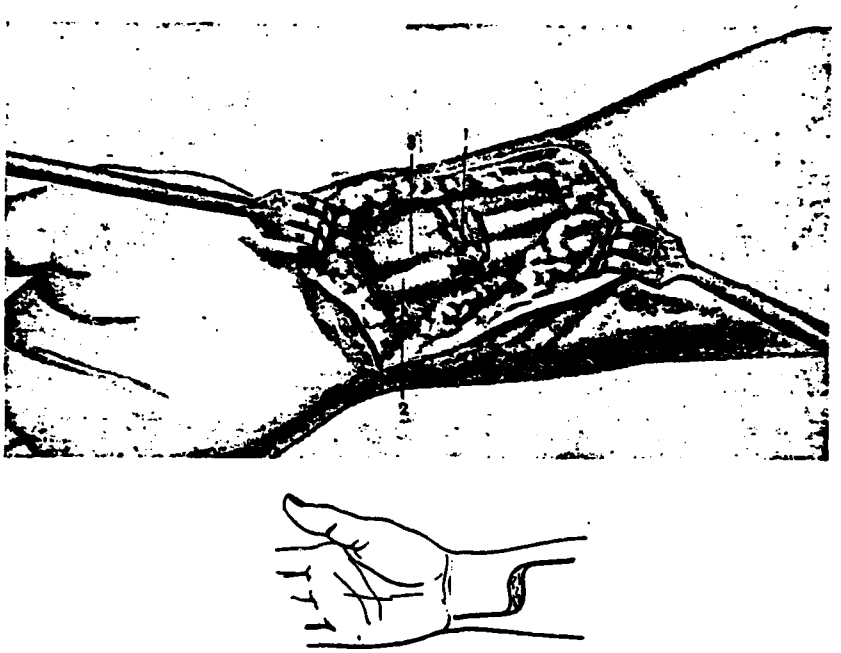


Fig. 92. Extraprojectional approach to the median nerve near the radiocarpal articulation: the skin flaps together with the subcutaneous fatty tissue are separated from the fascia of the forearm and pulled back to the sides.

1 - scar in the fascia; 2 - long palmar muscle; 3 - radial flexor of the hand.

## The operative approach to the ulnar nerve

Firearms injuries to the ulnar nerve were characterized by a relatively frequent combination of its injury with fractures of the humerus and particularly of the ulnar articulation. At

the forearm, combined injuries of the nerve with the artery of the same tame are characteristic. These types of injuries were reflected in the methods of operative interventions and the times of operation, which is evident from the materials for the development of illness histories (table 22).

It follows from table 22 that neurolysis of the ulnar nerve after a firearms wound was performed within a period of up to three months in over half the cases (53.3%), while in a period of from 3 to 6 months it was performed in 38.4%, and in a period of from 6 to 12 months it was performed only in singular cases -- in 5.0%. Figures close to this characterize total nerve resection with subsequent suture. Partial nerve resection was performed at later periods, specifically from 3 to 6 months -- in 52.4%. This is fully understandable, since partial injury of the nerve trunk is more difficult to diagnose.

Table 22 /228

Distribution of the frequency of operative interventions with injury to the ulnar nerve depending on their character and times (in percentages)

| Character of operation | Times of operations | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | 53.3 | 91.7 | 96.7 | 100.0 |
| Partial nerve resection | 33.3 | 85.7 | 100.0 | -- |
| Complete nerve resection..... | 44.6 | 92.9 | 100.0 | -- |
| Total.... | 45.3 | 90.7 | 98.7 | 100.0 |

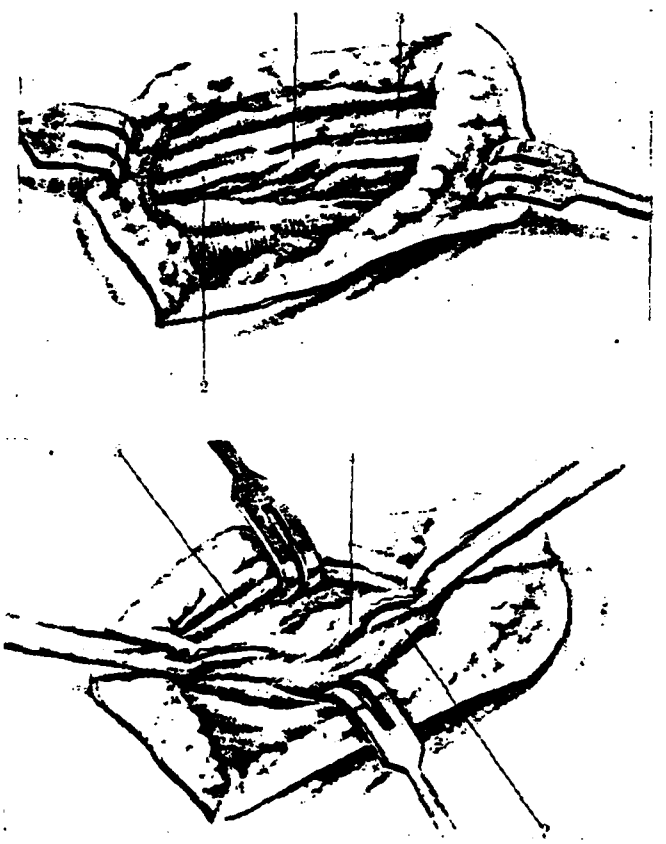

Fig. 93. Extraprojectional approach to the median nerve in the lower third of the forearm; fascia of the forearm is dissected.

1 - deep scars in the area of the forearm tendons; 2 - long palmar muscle; 3 - radial flexor of the hand; 4 - cicatrical tissue and neuroma connecting the ends of the wounded median nerve.

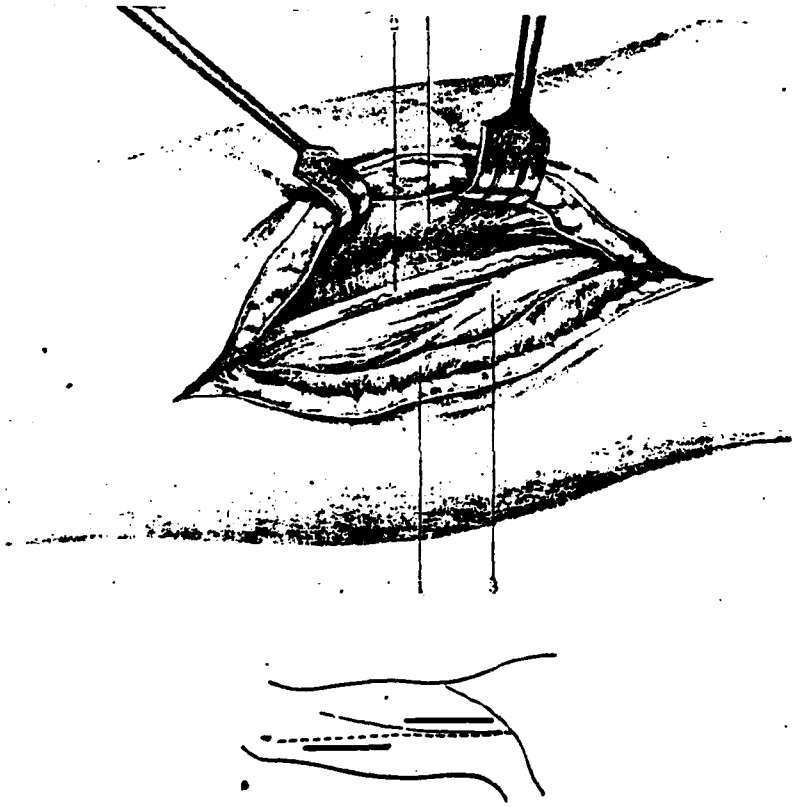

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Fig. 94. Approach to the ulnar nerve in the upper third of the brachium and at the boundary of the middle and lower third. The skin and the fascial sheath of the triceps muscle of the brachium are opened.

1 - edges of the fascial sheath of the triceps muscle of the brachium; 2 - ulnar nerve; 3 - internal edge of the triceps muscle.

The fascia is opened to the inside and somewhat to the /230 front of the point of cutaneous dissection. The external edge of the internal head of the triceps muscle, adjoining the intermuscular septum, is found. The triceps muscle is pulled away from the latter and the ulnar nerve is isolated (fig. 94).

After the appropriate operative interventions on the nerve, its muscular coverage is provided by means of the internal head of the triceps muscle with subsequent restoration of the fascial sheath of this muscle bed.

Approach to the ulnar nerve in the region of the cubital fossa. Injury to the ulnar nerve in this area is observed more often than in other areas, particularly with simultaneous injury to the ulnar articulation. In these cases during resection of the joint there are often discovered disruption in the integrity of the nerve trunk, compression of the ulnar nerve by bone fragments, dislocations of the nerve, and comparatively great defects in the nerve trunks. For operative approach to the ulnar nerve, it is recommended that an incision be made to the outside of the internal condyle, consequently to the front of the nerve projection (fig. 95). The projectional incision is drawn in the depression between the internal condyle and the olecranon.

With the extraprojectional incision the dissected skin is pulled back behind the internal condyle and the fascia is cut at the very condyle. This manipulation protects the nerve from injury during the operation in the osteal alveus. Pulling back the fascia partially with the sharp, partly with the blunt method, the nerve is isolated (fig. 131 and 132).

From the proposed incision with the presence of large defects it is easy to isolate the nerve in the lower third of the brachium and in the upper third of the forearm. Moving the

nerve into the anterior bed and flexing the ulnar articulation, the nerve is sutured without particular tension. To cover the nerve in case of its displacement, the internal brachial muscle and the pronator teres of the forearm are used. The latter must be lifted or dressing forceps are used to make a canal (fig. 131 and 132).

Fig. 95. Direction of cutaneous incisions for extraprojectional approaches to the ulnar nerve.
1 - in the area of the internal condyle;
2 - in the area of the forearm.

The approach to the ulnar nerve on the forearm. The ulnar nerve on the forearm is approached by incision along the Pirogov line, which connects the internal condyle of the humerus and the pisiform bone (fig. 95).

In the upper third of the forearm, the nerve lies under /231 a group of flexor muscles which begin here. The ulnar nerve is found in the fissure between the edges of the ulnar flexor of the hand on the one side and the superficial digital flexor and long palmar muscle on the other. This intermuscular space is

determined by a white strip. Here it is even necessary to use a knife to separate and section the edges of the named muscles into fibers. For quick, precise and sure exposure of the nerve, it is always necessary in preparation to adhere to the external edge of the ulnar flexor of the hand. The wound is strongly pulled apart with forceps and the ulnar nerve exposed, although sometimes not along its entire extent (fig. 68). Often the nerve is visible only in the lower half of the wound through a thin sheet of deep fascia. In the upper part of the wound the nerve remains covered for an extent of 3-5 cm by aponeurotic expansion of the ulnar flexor of the hand (fig. 131). Only after dissection of this aponeurotic layer does the ulnar nerve become fully visible above a grooved probe or mouse-tooth forceps (V. F. Zabrodskaya).

This method has great significance in the presence of severe injuries in the upper third of the forearm, when the anatomical relationships are sharply disrupted (fig. 132).

During operations on the middle third of the forearm, the skin upon dissection is retracted to the outside, the fascia of the forearm opened, and the external edge of the ulnar flexor of the hand is found. The ulnar neurovascular fascicle is found in the depth between this edge and the head of the superficial digital flexor. The nerve being sought lies to the inside of the artery in the fascial bed on the deep digital flexor.

Access to the ulnar nerve in the area of the radiocarpal articulation. With injuries near the radiocarpal articulation, the nerve is found with the aid of an incision drawn from the pisiform bone along the outside edge of the hand. Upon dissection of the skin, the short palmar muscle which is transversely located is isolated. Its fibers are intersected at the internal edge of the hand and retracted to the outside. The ulnar nerve and the artery are found in a special canal over the transverse palmar

ligament. Great care is required, since here the nerve is divided into three main branches. Of these, two are more superficial, leading to the lateral edges of the digits, and one is deep and supplies the small muscles of the hand. The peripheral end of the deep branch sometimes must be exposed in the depth between the short abductor and flexor muscles of the V finger (fig. 69, 70, 71, and 72).

With injuries below the pisiform bone, where the nerve has already diverged, it is necessary to isolate all three peripheral branches and to suture them with the trunk of the ulnar nerve. Coverage of the sutured nerve is provided in this case by the fibers of the short palmar muscle, the fascia and the cutaneous flap. Operative intervention in this area requires great care and is considered to be very difficult.

Operative access to the radial nerve

Firearms wounds to the radial nerve are for the most part combined with wounds to the humerus, often accompanied by severe osteomyelitis. Not so rarely noted were combined injuries of the radial nerve and the brachial artery. This character of injury to the radial nerve was reflected to a certain degree on the methods of operative interventions undertaken and on the times of operation, which is evident from the materials for the development of illness histories (table 23).

Table 23 /232

Distribution of the frequency of operative interventions with injury to the radial nerve depending on their character and times (in percentages)

| Character of operation | Times of operation | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | 44.3 | 94.3 | 100.0 | -- |
| Partial nerve resection | 57.1 | 100.0 | -- | -- |
| Complete nerve resection..... | 36.9 | 91.0 | 100.0 | -- |
| Nerve resection without suture..... | 25.0 | 100.0 | -- | -- |
| Total.... | 38.5 | 90.1 | 100.0 | -- |

From table 23 it is evident that partial resection of the radial nerve after firearms wounds was performed in a time of up to 3 months in over half the cases (57.1%). By 6 months time, all partial resections of the radial nerve had been concluded. It is also characteristic that by 6 months time the number of all operative interventions equalled 90.1%. This once again confirms the role of proximate specialized aid to the front line region, which made it possible to operate on the radial nerve in the first 6 months after the wound was sustained.

With a high level of injury to the radial nerve at its exit from the brachial plexus, exposure of the radial nerve is done according to the same rules as the exposure of the brachial plexus below the clavicle, as described above.

With a high level of injury to the radial nerve on the shoulder, the projectional approach to it is performed according to the method of A. Yu. Sozon-Yaroshevich. The cutaneous incision

runs from the deepest point of the axillary fossa to the middle of the brachium along the internal sulcus of the biceps muscle.

After dissection of the skin together with the subcutaneous fatty tissue and the superficial fascia, the bed of the biceps muscle is opened and the latter is pulled back to the outside. The bed of the neurovascular fascicle connected with the dorsal layer of the muscle sheath is disrupted (Pirogov). The entire neurovascular fascicle is retracted toward the front and toward the outside and the radial nerve is exposed, lying on the long head of the triceps muscle (fig. 85 and 86).

The approach to the radial nerve by means of dissecting the sheath of the neurovascular fascicle used by numerous doctors during this war is subject to criticism, since it does not provide a broad access and is very traumatic, particularly in the presence of massive scars which develop after firearms wounds. With this approach, the sheath of the neurovascular fascicle is disrupted, The median nerve and the brachial artery are retracted to the outside and upward, while the ulnar nerve and the brachial vein -- to the inside and downward. If it is impossible to isolate the radial nerve by this means, an additional temporary intersection of the long head of the triceps muscle is performed.

The least traumatic approach to the radial nerve in the upper third of the brachium is the extraprojectional. The cutaneous incision 10 - 12 cm in length is begun above the latissimus dorsi and the musculus teres major, runs obliquely and in a posterior direction at a distance of 1.5 - 2 cm from the internal sulcus of the brachium (fig. 96). Upon dissection of the skin, the subcutaneous fatty tissue and the superficial fascia, the latter is sectioned and retracted toward the back. Also opened here is the fascial sheath of the triceps muscle bed (fig. 96). The triceps muscle is sectioned away from /233

the fascia and its external edge is separated from the bone. Pulling the muscle away from the bone with blunt forceps, the radial nerve is easily exposed for the extent of the entire upper third of the brachium (fig. 97).

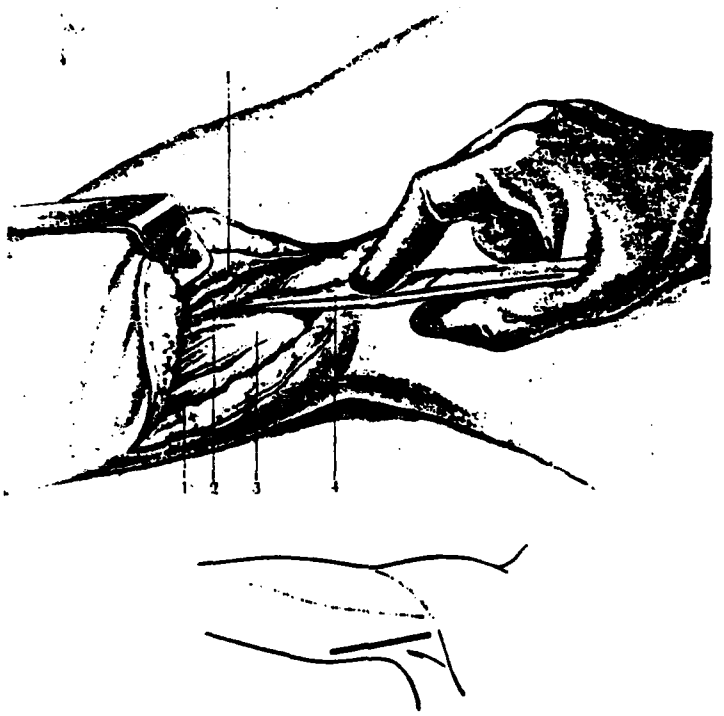



Fig. 96. Extraprojectional access to the radial nerve in the upper third of the brachium. The skin and fascia covering the triceps muscle are opened. Mouse-tooth forceps are used to separate the long head of the triceps muscle of the brachium from the humerus.

1 - fascia; 2 - neurovascular fascicle of the brachium covered with fasciose sheath; 3 - long head of the triceps muscle of the brachium.

This method makes it possible to broadly and least traumatically expose the nerve with all its branches. The isolation of the latter may also be spread in a central direction by means of dissecting the epineurium, which is practically important for retaining the innervation of the triceps muscle. The approach to the radial nerve from the inside in the case of its high injuries in the upper third of the brachium is rational, since it is conditioned by the anatomical position of the nerve. The use of the "posterior" approach to the radial nerve in this case may lead to error. The following case is particularly indicative.

> In 1943 on wounded patient Zh., the posterior access was used for high injury to the radial nerve. During the operation it turned out that the radial nerve was intact and was cicatricized. Neurolysis was performed. Due to the absence of regeneration, the patient was again operated with the application of the described extraprojectional approach to the radial nerve. A defect of over 2 cm was found in the nerve. A sizeable neuroma was isolated on the central end of the nerve. However, the peripheral end of the nerve was tightly fixed to the bone and evidently in the first operation, which did not correspond topographically to the level of injury, gave the impression of an undamaged nerve trunk. /234

The expediency of the described incision also consists in the fact that if during the operation performed by internal incision it turns out that the injury to the radial nerve spreads to the periphery, the cutaneous and fascial incision may be prolonged to the posterior side of the brachium. Here in the next intermuscular fissure -- between the long and external head of the triceps muscle -- the radial nerve is to be found (fig. 98 and 99).

The posterior incision for approach to the radial nerve is used in cases of radial nerve injury in the middle third of the brachium. The skin is dissected by an incision 10 - 15 cm long running from the middle of the posterior edge of the deltoid

muscle to the external sulcus of the biceps muscle (fig. 98).

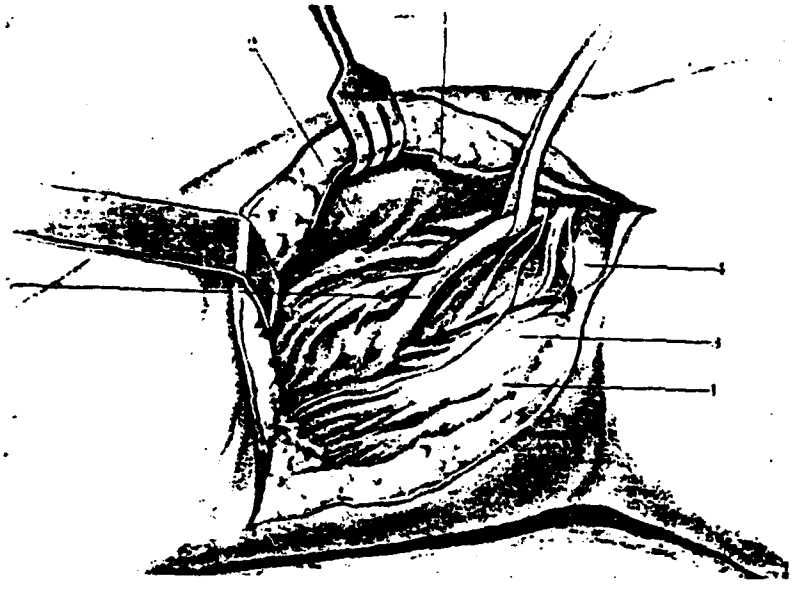


Fig. 97. Access to the radial nerve in the upper third of the brachium: the long head of the triceps muscle is separated from the bone, the radial nerve is isolated together with the muscle branches.

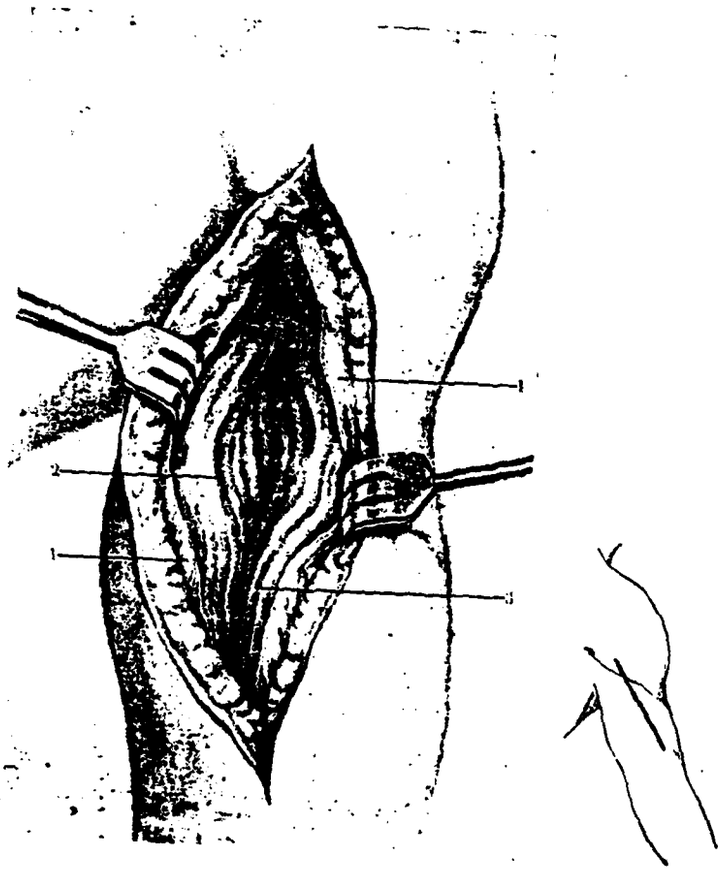
1 - fascia; 2 - neurovascular fascicle, covered with fascia of the humeroradial muscle; 3 - long head of the triceps muscle; 4 - tendon of the teres major and latissimus dorsi; 5 - radial nerve.

Some authors propose that an incision of from 20 cm in length be made directly along the back side of the brachium. The dissected skin and subcutaneous fatty tissue with the superficial fascia is retracted to the sides. The aponeurotic muscle sheath is opened above the center of the external head of the triceps muscle down to the fascial sheath of the deltoid

muscle. After this, separating the fascial sheath, the space between the long and external head of the triceps muscle is found, the bellies of the triceps muscle are sectioned and /235 divided in the direction toward the bone for the entire extent of the wound. The edges of the wound are widely retracted with forceps. Usually at first the posterior cutaneous nerve of the forearm is found, then the branch of the radial nerve which has already diverged from the main trunk, and then the radial nerve itself (fig. 99). It lies in the depth of the wound on the bone, in a thin neurovascular sheath. Sometimes in isolating the nerve from the sheath there is rather profuse hemorrhaging from the branches of the deep artery and brachial vein located nearby. The hemorrhaging must be thoroughly (!) stopped, the major branches are ligated, and the minor ones -- coagulated.

The extent of the nerve on the back side of the brachium /236 at the point where it curves around the bone is the shortest and is equal to from 4 to 6 cm. However, it is here that attempts are most often made to expose the nerve, which are successful if its integrity has not been disrupted. However, this is very difficult to do after severe firearms injuries when the ends of the radial nerve disappear under the long head of the triceps muscle and into the bed of the humeroradial muscle due to the nerve's elasticity. Therefore it is especially important here to isolate the central and peripheral end of the damaged nerve separately in order to draw a correct conclusion as to the character of the injury.

However, if the nerve is compressed by a bone callous in the middle third of the brachium, specifically the posterior is always indicated.



/235

Fig. 98. The posterior approach to the radial nerve: the direction of the cutaneous incision for the approach to the radial nerve. The skin and fascia are dissected, the muscular heads of the triceps muscle are moved aside.

1 - brachial fascia; 2 - long heads of the triceps muscle of the brachium; 3 - median head of the triceps muscle of the brachium.

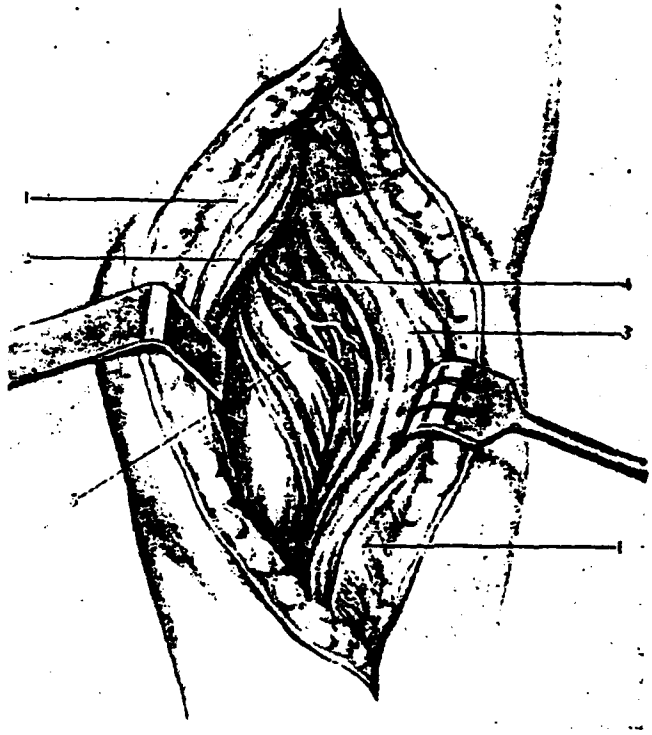


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Fig. 99. Posterior approach to the radial nerve. The heads of the triceps muscle are moved aside.

1 - fascia of the brachium; 2 - long heads of the triceps muscle; 3 - central head of the triceps muscle; 4 - deep brachial artery; 5 - radial nerve.

Exposure of the radial nerve at the anterior-exterior surface of the brachium (in the cubital fossa). With the projectional approach, an indision 10-12 cm in length is made along the course of the radial nerve. The skin and subcutaneous fatty tissue are dissected along with the superficial brachial fascia. The vein and the external cutaneous nerve of the forearm which are encountered in the subcutaneous fatty tissue are carefully /237

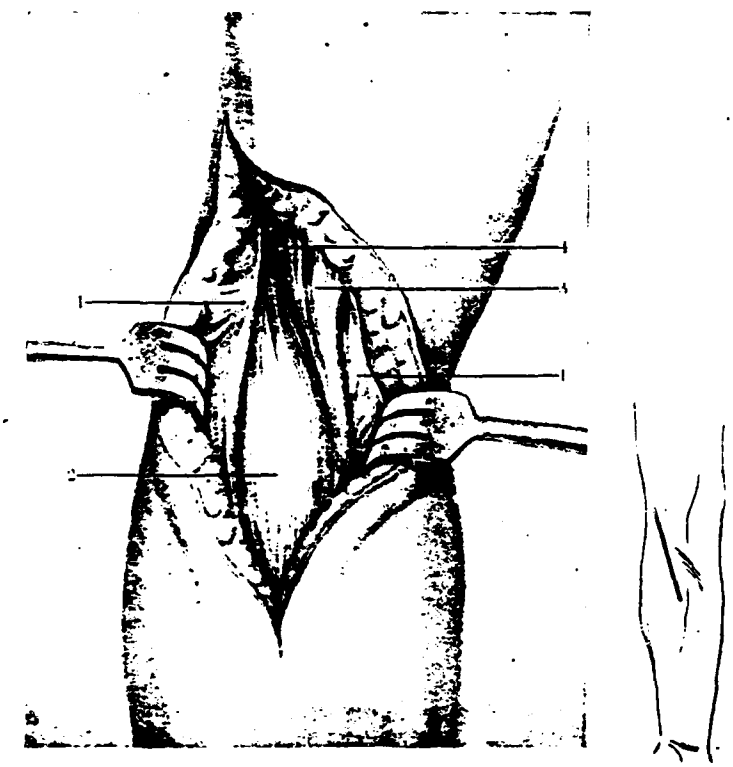

Figure. 100. Access to the radial nerve in the upper third of the forearm. Direction of the skin incision for an approach to the radial nerve in the region of the cubital fossa. The skin and fascia of side bed of extensors of forearm are opened up.
1 - fascia; 2 - musculus brachioradialis; 3 - biceps muscle; 4 - internal arm muscle.

retracted to the side. Then the brachial aponeurosis is dissected at the interval between the brachioradial and the brachial muscles.

It should be noted that the space between the given muscles is always more clearly expressed in the initial area of the brachioradial muscle, and lower the muscular fibers of the brachioradial and brachial muscles are so closely placed that sometimes it is difficult to find a fissure between them. The edges of the wound are retracted with blunt surgical hooks and the radial nerve is found in the space between these muscles at a distance of approximately 2-4 cm from the skin surface.

The radial nerve is located at the internal surface of the brachioradial muscle and is separated from the brachial muscle by a thin fascial sheet, which separates the anterior bed of the brachium from the lateral bed of the hand extensors.

The extraprojectional approach to the radial nerve in the /238 lower third of the brachium and the upper third of the forearm (cubital fossa). To expose the nerve in the lower third of the brachium, a large cutaneous incision 12-13 cm in length is made which runs above the middle of the brachioradial muscle. After the skin and subcutaneous fatty tissue are dissected, the fascial muscle sheath is opened to the inside of the cutaneous incision and the internal edge of the brachioradial muscle is located. The latter is retracted to the outside and the radial nerve is isolated in the depth.

This incision is more expedient than the generally accepted one which runs along the groove between the brachioradial and the brachial muscles, since the latter does not always ensure the exposure of widely divergent nerve endings. Upon exiting from under the external head of the triceps muscle, the radial nerve enters the sheath of the lateral extensors, which it innervates and with which it is consequently always intimately /239 connected, even in the most severe injuries.

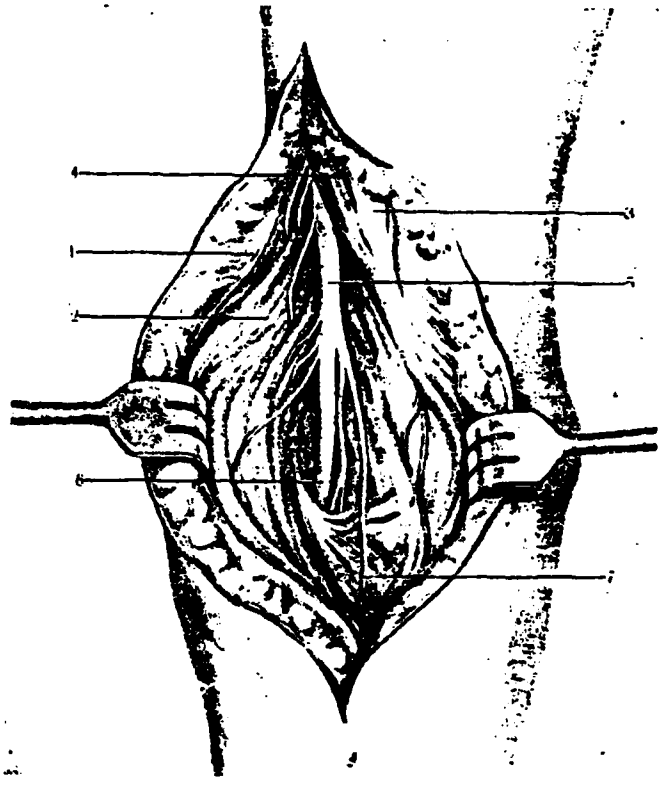

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Fig. 101. Access to the radial nerve in the upper third of the forearm. The brachioradial muscle is retracted to the outside. The point of division of the radial nerve is exposed.

1 - fascia of the forearm; 2 - the brachioradial muscle retracted to the outside; 3 - biceps muscle; 4 - internal brachial muscle; 5 - radial nerve; 6 - deep muscular branch of the radial nerve before entering the supinator canal; 7 - superficial branch of the radial nerve.

To expose the deep muscular branch of the radial nerve /239 in the lower part of the cubital fossa, the above-described incision over the brachioradial muscle is prolonged by 6-7 cm. The fascia is opened up to the inside of the cutaneous incision, and the anterior edge of the brachioradial muscle is isolated. The latter is retracted sharply to the outside, and the supinator is found under it.

Tracing the radial nerve exposed at the edge of the brachioradial muscle, it is easy to find the point of its division into the superficial cutaneous branch and the deep locomotory branch which enters the supinator. In order to find the deep branch and restore its integrity, sometimes it is necessary to dissect the supinator by fibers, opening the radial nerve channel in it (fig. 101).

Exposure of the superficial branch of the radial nerve is done by means of an incision running over the brachioradial muscle closer to its internal edge. There is no need to seek the superficial branch between the brachioradial muscle on the one hand and the pronator teres and radial flexor on the other, as this is usually described, since the superficial branch is accompanied at all times by the brachioradial muscle and does not lie in the same bed with the radial artery. The latter remains behind the fascial septum and is not in the field of vision. The exposure of the superficial cutaneous dorsal branch of the radial nerve is done by a cutaneous incision running above the tendon of the brachioradial muscle. The skin is dissected, the fatty tissue at the external edge of the muscle tendon is carefully sectioned, since the superficial cutaneous dorsal branch, penetrating the muscular aponeurosis, is located under the superficial fascia (fig. 73-75).

The projection of the main trunk of the superficial cutaneous dorsal branch of the radial nerve runs from the edge of the brachioradial muscle to the head of the II metacarpal bone.

Exposure of the deep muscular dorsal branch of the radial nerve in the bed of the forearm extensors needs to be done very rarely. The branches of the radial nerve here are very thin. Therefore, if the injury occurred in this area, it is very difficult to find them in the scars. We may also spead of the approach to the radial nerve in the lower portion of the supinator canal to the point of division of the nerve into peripheral muscular branches.

To expose the radial nerve in this area, a 10-12 cm long incision is made which runs from the external condyle vertically downward. The dissected skin and subcutaneous fatty tissue are retracted to the sides, the fascia of the posterior bed of the forearm is opened, and the fissure between the common digital extensor and the ulnar extensor of the hand is found. The indicated muscles are separated to the very condyle and retracted with hooks. The edge of the supinator is exposed, near which the dorsal deep muscular branch of the radial nerve is isolated.

## The anatomo-topographical specifics of the nerves of the lower extremity and their significance in operative accesses

The experience of the Great Patriotic War has shown that the nerves of the lower extremities are damaged less frequently than those of the upper extremities. Aside from the difference in the relations of the individual anatomical elements of the extremity with the number of large nerve trunks, an explanation for this fact may also be certain specifics in the structure of the latter. Thus, of the four main nerves of the lower extremity: the sciatic, the femoral, the obturator and the external cutaneous femoral nerve, the latter three are divided high, in the pelvic cavity /240 and on the femur they are found sometimes only in the form of comparatively small branches, usually crossing each other. This

is also reflected in the materials for the development of illness histories , which showed that injuries to the indicated three nerves were observed exceedingly rarely. Even the most frequent of these -- injuries to the femoral nerve -- were noted, according to the materials for the development of illness histories, in 1.16% of the cases and occupied one of the last places among nerve injuries. The only nerve whose main trunk has sufficient extent is the sciatic nerve, whose injuries in frequency occupied second place (14.9%) in the Great Patriotic War according to the materials indicated above.

At the same time, access to the nerves of the lower extremity is more complex, since they usually lie deep and are often covered with thick layers of muscles. Only by knowing the exact topography and differences in the position of the nerves is it possible to expose such a "hidden" nerve as the obturator. This is particularly necessary to know in access to the lumbar plexus.

The differences observed in the external structure of the lumbosacral plexus become more understandable with an analysis of the specifics of development of the caudal area of the spinal cord.

In the process of evolution, the spinal cord undergoes changes, one of the expressions of which is its reduction in a cranial direction. However, this process does not always take place uniformly, and the reduction may be held back at intermediary stages of development. This position is confirmed not only by anatomical, but also by histological data. Thus, V. L. Blumenau indicates the "individual deviations, as a result of which the same group of motor cells may lie in the spinal cord of some individuals a half segment or a whole segment above the

standard level, and in others -- below it".

According to the data of G. S. Kagan, the apex of the medullary cone in adult humans is variably located. In dolichomorphic persons it is found at the level of the upper third of the I lumbar vertebra, while in brachiomorphic persons it is located at the level of the lower third of the second. The level of root formation also varies similarly. Most often the first lumbar root diverges from the beginning of the lumbar enlargement, but in brachiomorphic persons it is the eleventh thoracic. From the point of greatest enlargement in the latter persons it is the fourth lumbar root which is divergent, but in dolichomorphic persons -- it is the first sacral. These differences cannot help but be reflected in the formation of the plexus.

The lumbar plexus is often united with the sacral into a single lumbosacral plexus. This is understandable, since all the complex stages in the processes of development are expressed to a more or less uniform degree in the form and specifics of both these formations. However, their separate description in this case presents a certain convenience.

It is usually considered that the anterior branches of the twelfth thoracic, first, second, third and fourth lumbar roots participate in the formation of the lumbar plexus. The anterior branches of the first, second and third lumbar roots enter completely into the composition of the plexus, while the twelfth thoracic and the fourth lumbar -- only partially. However, this scheme does not always correspond to reality.

The observed differences are, in the first place, a reflection of the different degree of displacement of the lumbar plexus in the process of development. According to the data of

O. S. Semenova, with cranial displacement the composition of the plexus includes not only the greater part of the anterior branch of the twelfth thoracic root, but also partially the eleventh /241 thoracic. With caudal displacement, the anterior branch of the twelfth thoracic root does not participate at all in the formation of the plexus, and its upper limit begins from the level of the first lumbar root. The lower level is equally variable. With cranial displacement, the fourth lumbar root participates in the formation of the lumbar plexus only partially, while most of it enters into the composition of the sacral. However, with caudal displacement, the anterior branch of the fourth lumbar root enters wholly into the lumbar plexus, and moreover the anterior branch of the fifth lumbar nerve also participates in the formation of the latter.

Specifics of the caudal area of the plexus are also the form and degree of expression of the n. furcalis, i.e., the most caudal nerve entering into the lumbar plexus, in cases when it has the form of a tricuspid and a connection with the sacral nerve. The mass of n. furcalis (three cusps) is distributed between the femoral and the obturator nerve, as well as the truncus lumbo-sacralis, which is the connecting link between the lumbar and the sacral plexus and may also be variably expressed. N. furcalis more often corresponds to the fourth and fifth lumbar root. However, depending on the varying degree of displacement, it may emerge from the third or fifth root. In extremely rare cases it may be absent altogether, and then the connection between the lumbar and sacral plexus is absent.

Differences in the structure of the lumbar plexus are also expressed in the non-uniform number of roots entering into its composition. In some cases their number is equal to four, and in others it may increase to six. The variability of the lumbar

plexus is also manifested in the fact that with one extreme form the roots converge at a sharper angle than with another. The nerves lie closer to each other and are directed downward more vertically (A. Yu. Sozon-Yaroshevich).

The sacral plexus. Everything which has been said of the lumbar plexus may to a considerable degree be related also to the sacral. Cranial displacement of the lower limit of the former is the same for the upper edge of the latter.

The structure of the sacral plexus varies. With one (dispersed) form, it consists of six roots and represents a wide multi-looped network. Here a high beginning of the trunks emanating from it is observed. With another (concentrated) form, the formation of the plexus includes four roots. The plexus has a compact appearance, almost without loops, and gradually goes into the sciatic nerve (A. Yu. Sozon-Yaroshevich).

The differences in the structure of the lumbosacral plexus usually correspond with the specifics in the formation of the nerves diverging from it.

The femoral nerve is considered to be the thickest of all the terminal branches of the lumbar plexus. Its inception may vary according to the number of peduncles and according to their affinity to the corresponding lumbar roots. Thus, sometimes in the formation of the femoral nerve there are two peduncles, while in other cases their number increases to 4-5. The composition of the femoral nerve may include the anterior branches of all the lumbar roots and even the twelfth thoracic. However, it usually begins with three peduncles from the anterior branches of the second, third and fourth lumbar roots.

The trunk of the femoral nerve is usually formed in the thickness of the greater round psoas muscle at the level of the V lumbar vertebra. Further it proceeds obliquely downward and to the outside in the groove between the above-mentioned and /242 the iliac muscle and exits to the femur through the lacuna musculorum. Below the Poupart's ligament the nerve sometimes adjoins the femoral artery and is separated from it only by a fascial layer. In other cases the distance between them may reach up to 3 cm. More often it equals 1-1.5 cm. This is significant in combined injuries to the femoral nerve and the femoral artery, which, according to the materials for the development of illness histories, are noted in 3.3%.

Sometimes an additional femoral nerve is observed, which is located 2-3 cm to the outside of the main trunk. It begins with one, two or three roots. In the latter case, one root is formed from the $L_2$, another -- from the connective loop between $L_2$ and $L_3$, and the third -- from the femoral nerve. The trunk of the auxiliary nerve may be singular or double. On the thigh it is usually joined with one of the anterior cutaneous branches and supplies a small area under the Poupart's ligament. However, in some cases it occupies a more extensive zone on the medial or on the anterior surface of the thigh. If an auxiliary nerve is present, it is connected with the femoral nerve in the pelvis and in the limits of the Scarpa's triangle by singular or double connections.

In the pelvis, the femoral nerve gives off muscular branches. A thin branch diverges from its upper part, which is located on the anterior surface of the greater round psoas muscle and penetrates into the latter near Poupart's ligament (above or below it). The iliac muscle receives 2-3 branches which diverge from the external edge of the femoral nerve. With caudal displacement of the plexus, an additional branch is often observed to the extra-pelvic portion of the muscle. At the level of Poupart's ligament or slightly below it, a branch diverges from the femoral

nerve to the pectineal muscle. It passes behind the femoral vessels and penetrates into the anterior surface of the muscle.

The division of the femoral nerve takes place at various levels -- from 3 cm above the Poupart's ligament to 5 cm below it. According to the materials of N. S. Korotkevich and Balakiyeva, the femoral nerve is usually divided into three main fascicles: the anterior, the lateral and the medial. In some cases this division takes place at one level, and in others -- first the anterior fascicle diverges from the main trunk, and then (at a distance of from 0.5 to 4 cm) the two remaining ones are formed. Thus, with injuries below the Poupart's ligament, it is not the common trunk of the femoral nerve which may be injured, but rather its isolated fascicles.

Diverging from the anterior fascicle are branches to the tailor's muscle and to the skin. In rare cases some of the cutaneous branches begin directly from the trunk of the femoral nerve. Part of them (1-3 branches) usually passes through the thickness of the tailor's muscle, lodging in the duplicature of the broad fascia of the thigh, penetrating it at various levels and branching in the subcutaneous fatty tissue of the anterior surface of the thigh. Other branches come out into the subcutaneous fatty tissue at a distance of from 5 to 17 cm below the Poupart's ligament and spread to the anterior-external surface of the thigh, reaching the patella (fig. 102). The branches which are located more medially penetrate the broad fascia of the thigh 7-8 cm below the Poupart's ligament. Within the limits of the Scarpa's triangle they intersect the femoral vessels and branch in the subcutaneous fatty tissue of the medial surface of the thigh. Proximally located nerve branches usually pass behind the vessels, and those which are more distally located -- in front of them. Sometimes they surround the vessels in a loop or are located between the artery and the vein. One

of the branches often accompanies the femoral artery, being located on its anterior-interior surface.

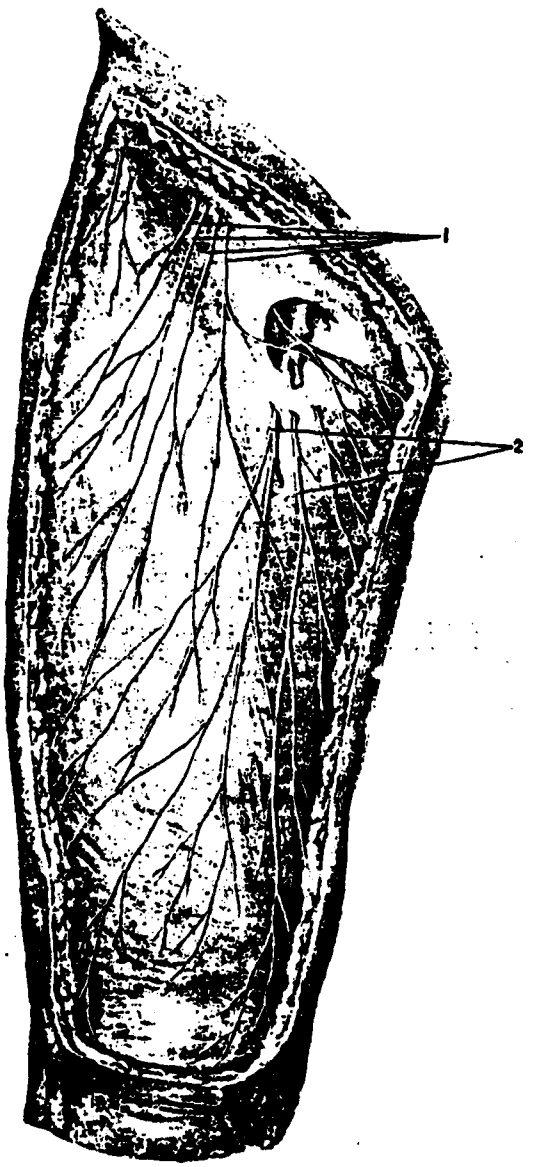


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Fig. 102. Subcutaneous nerves of the anterior surface of the thigh with high division of the external cutaneous nerve.

1 - branches of the external cutaneous nerve of the thigh; 2 - anterior cutaneous branches of the femoral nerve.

In some cases the anterior cutaneous branches break up /244 immediately into a large number of thinner branches, and in others their number is small and they diverge gradually from the main trunk. The higher they appear in the subcutaneous fatty tissue, the smaller and shorter are the branches diverging off the neighboring nerves to the upper third of the anterior-medial surface of the thigh.

The lateral fascicle of the femoral nerve supplies the musculus rectus femoris and the exterior vastus muscle, the medial fascicle supplies the interior vastus muscle, as well as the skin of the anterior-medial surface of the shin and the foot, spreading in these areas in the form of its terminal branch -- the internal cutaneous nerve of the lower extremity.

The number of muscular branches of the femoral nerve, as well as the place of their approach to the individual muscles is not uniform. Thus, the tailor's muscle is usually supplied by 2-7 branches which diverge from the anterior fascicle of the femoral nerve, more rarely -- from the internal cutaneous nerve of the lower extremity (to the lower third of the muscle), and in individual cases -- from the lateral fascicle of the femoral nerve. All these nerves penetrate into the muscle from the interior or dorsal surface. The musculus rectus femoris and the exterior vastus muscles are supplied from the lateral fascicle. From 2 to 6 branches goes to each of them; to the musculus rectus femoris -- from the dorsal surface, and to the exterior vastus muscle -- from the medial.

Considerable inconstancy is noted in the nerve supply to the interior vastus muscle. Usually all of it is supplied from the medial fascicle of the femoral nerve. However, the branches to it may diverge from the medial and lateral fascicle, as well as from the internal cutaneous nerve of the lower extremity and from the lateral fascicle. The nerve branches in numbers ranging from 2 to 8 penetrate into the muscle from the anterior surface.

The musculus vastus medialis is innervated from the branches going to the exterior or interior vastus muscle.

The terminal branch of the femoral nerve -- the internal cutaneous nerve of the lower extremity -- begins from the medial fascicle to the inside of the branch going to the interior vastus muscle and, being directed downward, intersects the front of the a. and v. circumflexa femoris lateralis. At the apex of the Scarpa triangle this nerve approaches the femoral artery, lies on its anterior-exterior surface and together with it penetrates into the Hunter's canal. In some cases an auxiliary root from the anterior fascicle of the femoral nerve plays a role in the formation of this nerve, merging with the main trunk 3-10 cm distally from the Poupart's ligament. Sometimes this nerve loop surrounds the indicated vessels. In Hunter's canal the lateral branches diverge from the internal cutaneous nerve of the lower extremity and penetrate the wall of the canal, being directed to the medial surface of the lower third of the thigh and often reaching the center of the popliteal fossa. Diverging at the level of the medial condyle is the r. infrapatellaris. The latter may diverge above this level (up to 8 cm) or below it (by 3-4 cm). In some cases this branch winds around the tailor's muscle, passing along its anterior surface, and in others it penetrates the thickness of the indicated muscle. Its terminal branches spread in the area of the tuberositas tibiae, and sometimes go into the patella, the external surface of the knee joint area, and the upper third of the crus.

On the crus the internal cutaneous nerve of the lower extremity is located near the large subcutaneous vein (in front or behind it) and gives off a varying number of branches to the skin of the medial surface (rr. cutanei cruris medialis). Its terminal branchings spread within the limits of the medial edge of the foot, reaching in individual cases the base of the big toe. Still more rarely they spread to the area of the posterior portion of the /245

interior edge of the foot.

The character of branching of this nerve is inconstant. Thus, within the limits of the middle or lower portion of the crus it may separate into two trunks (sometimes this division takes place higher -- in Hunter's canal) or it may form loops as a result of the lateral branches which, passing a distance of from 3 to 6 cm, again join with the main trunk. Such loops are usually localized in the area of the crus, more rarely on the thigh.

There are connections between the individual branches of the femoral nerve. The connections between the anterior cutaneous nerves are observed usually in the upper third of the thigh, under the broad vascia, more rarely in the central and still more rarely -- in the lower third, and then they lie in the subcutaneous fatty tissue. Often there are noted connections between the anterior cutaneous branches and the internal cutaneous nerve of the lower extremity, which are found under the tailor's muscle or in the subcutaneous fatty tissue of the medial surface of the thigh. Connections are particularly frequent between the latter of the indicated nerves and that branch of the femoral nerve which runs along the artery of the same name (fig. 103).

A narrowing of the area taken up by the branches of the femoral nerve takes place due to the corresponding expansion of zones of branching of the lumboinguinal nerve, the external cutaneous nerve of the thigh, the external cutaneous nerve of the crus, and the superficial fibular nerve. Aside from such replacement of the individual areas of the region of the femoral nerve by neighboring nerves, areas of overlapping coverage may also be observed. Relatively frequently they are encountered in the upper third of the thigh with the lumboinguinal nerve and in the upper third of the crus with the external cutaneous nerve.

Thus, two extreme forms of changeability in the structure of the femoral nerve are manifested. In one, its division occurs below the Poupart's ligament, the main fascicles, which are longer, fall apart gradually into small branches. There are fewer muscular and cutaneous branches. The internal cutaneous nerve of the lower extremity also gives fewer branches. The r. infrapatellaris diverges at the level of the condyle of the femur or lower. The area taken up by the femoral nerve is relatively small (fig. 109). There are few connections.

In the second form of structure there is a high division of the femoral nerve, whose main fascicles break up rapidly into a large number of branches, and there are more cutaneous branches. An additional femoral nerve is observed, as well as a double trunk in the internal cutaneous nerve of the lower extremity. The latter is divided high into the r. infrapatellaris and a large number of internal cutaneous branches of the crus. There are numerous connections.

The external cutaneous nerve of the femur is formed from the lumbar plexus at various levels (from $L_1$ to $L_4$), most often from the loop between $L_2$ and $L_3$ there may diverge one, two or three peduncles. In rare cases it may diverge directly from the trunk of the femoral nerve.

Interest is presented by cases when the external cutaneous nerve of the femur begins with two peduncles, of which one diverges from the lumbar plexus, and the other from the femoral nerve or its anterior cutaneous branches. Directly at the point of formation the external cutaneous nerve of the femur is located under the greater roung psoas muscle or in its thickness. In the pelvis it lies on the iliac muscle, under the fascia of the same name. Then it passes under the Poupart's ligament, located 1 cm to the inside of the anterior-superior bone and in front of the deep artery surrounding the ilium. The indicated distance

may be increased up to 5 cm. Therefore, incisions to expose this nerve should more expediently be made in a transverse direction.

On the thigh the external cutaneous nerve descends vertically downward, passing for an extent of from 2 to 12 cm in the /246 thickness of the broad fascia and, penetrating it, branches in the subcutaneous fatty tissue of the anterior-external surface of the thigh.

The division of this nerve (into 2-5 trunks) occurs at various levels: in some cases -- above the Poupart's ligament, and in others -- at the level of it or below.

Between the external cutaneous nerve of the thigh and the neighboring nerves (the anterior cutaneous branches of the femoral nerve, the lumboinguinal and, more rarely, the ilio-inguinal) there may be observed connections on the thigh as well as in the pelvic cavity.

The area taken up by this nerve varies considerably by its place of location and by its size. In some cases the terminal branches end within the limits of the central third of the thigh, and then the lower half of it is supplied by means of well expressed anterior cutaneous branches of the femoral nerve (fig. 102). Often in the upper third of the thigh there is only the main trunk, which does not give any branches, and the entire mass of the peripheral branchings is located in the middle and lower third of the thigh. In these cases the external surface of the upper third of the thigh receives branches from the ilio-unguinal nerve (fig. 103). Sometimes the sphere of distribution of the external cutaneous nerve takes up the entire lateral surface of the thigh, reaching the kneecap, and in some cases it descends even more distally. The zone of this nerve is often covered by branches of neighboring nerves, particularly in the upper and middle third of the thigh -- by the lumboinguinal nerve.

Thus, according to the data of L. P. Yakovleva, there are two extreme forms of variability (differences) in the external cutaneous nerve of the femur. With one -- the main trunk is divided above the Poupart's ligament into a large number of branches, which spread in the upper half of the external surface of the thigh. In this case, the area taken up by them narrows as it proceeds downward. There are numerous connections with neighboring nerves. Another form is characterized by the presence of a long singular trunk from which branches diverge is successive order. Their sphere of distribution is displaced distally and expands in the direction toward the lower sections of the thigh. Connections with the neighboring nerves are rarely observed. In accordance with this, the zone of sensitivity disruptions with injuries to the trunk of the external cutaneous nerve of the femur is also not constant. In some cases it is located primarily in the upper regions of the thigh, and in others it is localized primarily in the lower regions, spreading sometimes to the crus. In rare cases, sensitivity disruptions with injuries to this nerve may be absent altogether due to coverage of this zone by branches of neighboring nerves.

The obturator nerve is formed from the second and fourth lumbar root. Aside from this, the first and fifth roots may participate in its formation. In exceptionally rare cases it may begin from the femoral nerve.

The merging of the indicated roots and the formation of the trunk of the obturator nerve takes place in the thickness of the greater round psoas muscle. Further, the nerve trunk exits near its external edge and descends along the lateral wall of the pelvis into the obturator canal. In this area the nerve lies on the parietal layer of the pelvic fascia, somewhat below the innominate line and above the obturator artery. It intersects the hypogastric vein, then the hypogastric artery and the ureter.

In the pelvis it gives branches to the internal obturator muscle, often to the external, and sometimes to the pectineal muscle, after which it divided into the anterior and posterior branch.

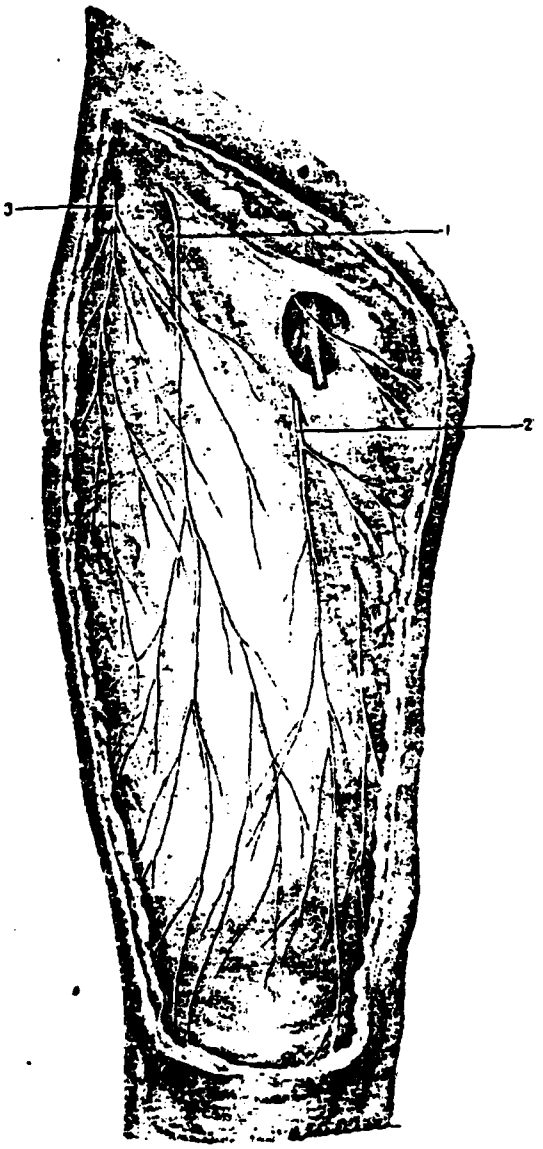


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Fig. 103. The subcutaneous nerves of the anterior surface of the thigh with low division of the external cutaneous nerve.

1 - external cutaneous nerve of the femur; 2 - anterior cutaneous branches of the femoral nerve; 3 - branches of the ilioinguinal nerve.

Usually this division takes place at the level of the /248
horizontal branch of the pubic bone, sometimes directly at the exit from the obturator canal (fig. 104). In exceptionally rare cases the obturator nerve splits into its terminal branches in the pelvic cavity (at the level of the sacroiliac joint).

In rare cases it is possible to note the presence of an additional obturator nerve, with the third, third-fourth or fourth lumbar root taking part in its formation. At the beginning of its path it runs along with the main trunk, then diverges from it, passes in front of the horizontal branch of the pubic bone and exits to the thigh under the Poupart's ligament. Further it penetrates under the pectineal muscle where it joins with the main trunk of the obturator nerve. In individual cases branches diverge from the auxiliary obturator nerve to the pectineal and external obturator muscle, and sometimes to the long adductor and the gracilis muscle.

The anterior branch of the obturator nerve, which is the larger one, is located on the short adductor muscle, and is covered by the pectineal and the long adductor muscle. It supplies the gracilis, the long and short adductor muscles, and sometimes also the pectineal (the short adductor muscle of the femur obtains an additional branch from the posterior branch of the obturator nerve, which comes up to its posterior surface).

The cutaneous branch diverges from the anterior branch of the obturator nerve or from one of its muscular branches. It lies between the gracilis and the long adductor muscle, penetrates the fascia and in some cases terminates at the level of the lower third of the thigh. In others it reaches the internal malleolus (O. S. Semenova, D. N. Lubotskiy). Sometimes within the limits of the lower third of the thigh or in the area of the medial surface of the knee joint this branch merges wholly

into the composition of the internal cutaneous nerve of the lower extremity. Connections may also be observed with the anterior cutaneous branches of the femoral nerve. In more rare cases the indicated cutaneous branch descends to the crus and is located 1-4 cm to the back of the internal cutaneous nerve of the lower extremity, exchanging fibers with it for the entire extent. In connection with the significant variability in the location of this branch, A. G. Molotkov calls it the "migrating branch".

The posterior branch of the obturator nerve supplies the external obturator muscle (the branches come up to the external surface of the muscle) and the adductor muscles -- the minor, the short and the major. Sometimes located in the thickness of the latter are connections between the obturator and the sciatic nerve. The described branch also participates in the innervation of the hip joint, and sometimes also the knee joint. Thus, two extreme forms in the structure of the obturator nerve are manifested. In one of them it diverges at a low level (after exiting the obturator canal), the branches separate in successive order (fig. 105 and 105a). The auxiliary obturator nerve is observed rarely. The cutaneous branch completely merges with the internal cutaneous nerve of the lower extremity at the level of the lower third of the thigh or at the medial surface of the knee joint.

In the other form of structure, a high division of the obturator nerve is observed (in the pelvis or in the beginning of the canal). Here its trunk separates into a considerable number of branches (fig. 104). The auxiliary nerve is often observed. The cutaneous branch is located on the crus and has multiple connections with the internal cutaneous nerve of the lower extremity.

The sciatic nerve. The level of formation of the sciatic nerve varies and usually depends on the position (displacement) of the lumbosacral plexus. These differences vary within the /249

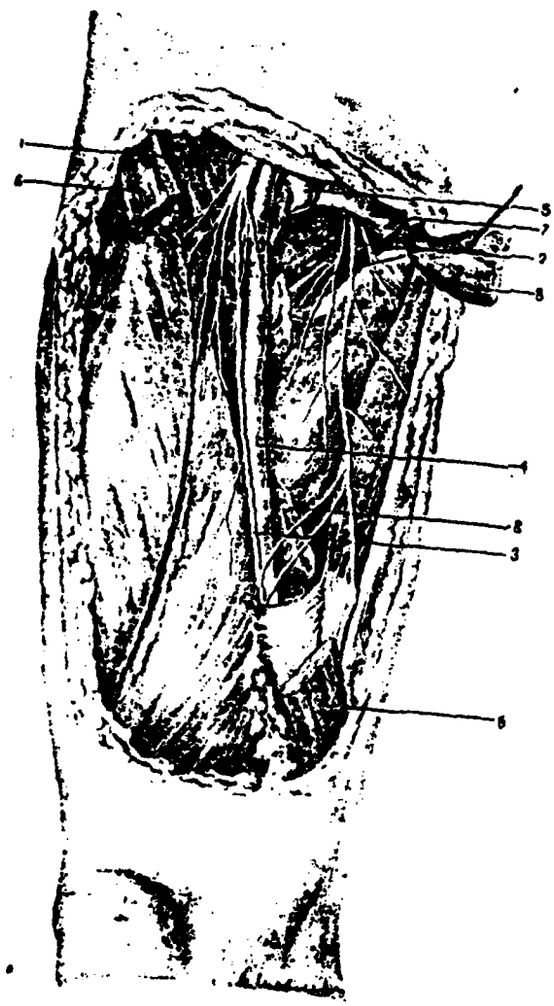


Fig. 104. High division of the femoral and obturator nerve.

1 - femoral nerve; 2 - branches of the obturator nerve; 3 - internal cutaneous nerve of the lower extremity; 4 - femoral artery; 5 - femoral vein; 6 - tailor's muscle; 7 - pectineal muscle; 8 - long adductor muscle.

limits of the fourth lumbar to the fourth sacral roots. With cranial location of the plexus, the sciatic nerve begins from the higher regions, and with the caudal form -- from the lower.

According to the data of L. P. Yakovleva, in some cases (with a compact plexus) the merging of these roots and the formation of the sciatic nerve into a thick trunk occurs in the /250

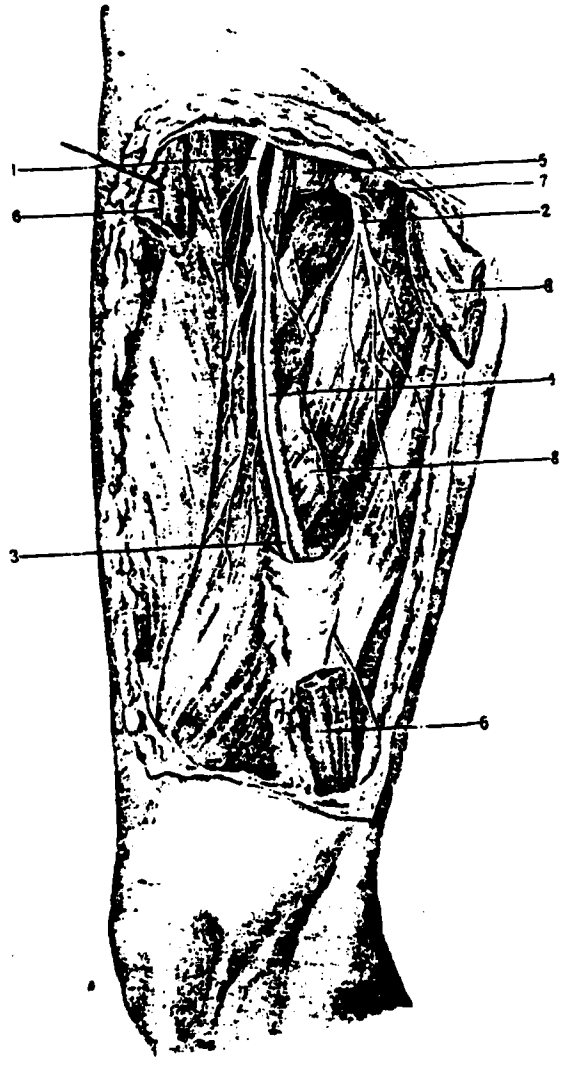


Fig. 105. Low division of the femoral and obturator nerve.

1 - femoral nerve; 2 - obturator nerve; 3 - internal cutaneous nerve of the lower extremity; 4 - femoral artery; 5 - femoral vein; 6 - tailor's muscle; 7 - pectineal muscle; 8 - long adductor muscle.

pelvic cavity, from which it exits from under the piriform muscle (through the foraman infrapiriformе). In other cases, (with a reticular structure of the plexus), two trunks of the sciatic nerve are observed, of which one exits through the /251

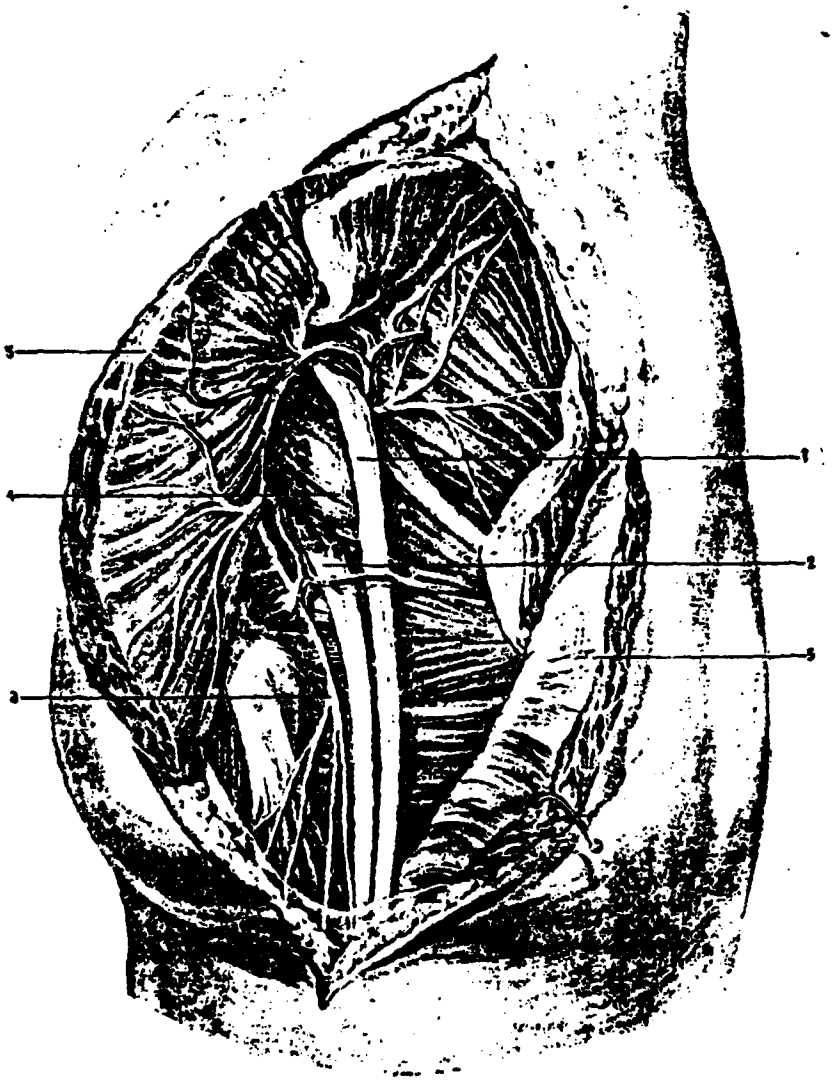

Fig. 105a. Low division of the femoral and obturator nerve.

1 - femoral nerve; 2 - obturator nerve; 3 - internal cutaneous nerve of the lower extremity; 4 - femoral artery; 5 - femoral vein; 6 - tailor's muscle; 7 - pectineal muscle; 8 - long adductor muscle.

foraman infrapiriforme (the tibial nerve), and the other through the foramen suprapiriforme or penetrates the thickness of the piriform muscle, exiting into the gluteal region through the mass of this muscle (common fibular nerve).

In the gluteal region the sciatic nerve lies to the /252 outside of the inferior gluteal artery, at the posterior surface of the internal obturator muscle, the gemellus muscles and the quadrate muscle of the thigh. The back of the nerve is covered by the gluteus maximus muscle and a deep fascial layer. It projects approximately half the distance between the sciatic tuber and the greater trochanter. At the exit from under the lower edge of the gluteus maximus, the nerve is located most superficially. Further it goes down under the long head of the biceps muscle, and then lies between the semitendinous and the semimembranous muscles on the one side and the biceps muscle on the other. The external edge of the latter slightly covers the nerve. The sciatic nerve is accompanied for its entire extent by an artery (a. comitans n. ischiadici) and by veins.

The sciatic nerve may be presented in the form of a compact trunk without clear limits between both of its portions (A. N. Maksimenkov). With a high division the latter may be located side by side in the common fascial or epineural sheath or may pass separately at a distance of 1-1.5 cm from each other. In the latter cases there may be isolated injuries to the tibial and fibular nerves on the thigh. The materials for the development of illness histories have shown that combined injuries to the tibial nerve and the femur (thighbone) are observed in 2.3% of the cases, and injuries of the fibular nerve and the femur -- in 3.0% of all cases of injury to these nerves.

Along the entire extent of the thigh, the tibial nerve lies more to the front and medially, and the common fibular -- to

the back and laterally. Upon exiting the pelvis, the sciatic nerve gives off branches to the gemellus muscles, to the internal obturator and to the quadrate muscle of the thigh, as well as branches to the bursa of the hip joint. In the upper third of the thigh, branches diverge from its tibial portion to the semitendinous and to the semimembranous muscle and to the long head of the biceps muscle, and from its fibular portion -- to the short head of the latter. In the presence of a solid trunk, the sciatic nerve is usually divided within the limits of the popliteal fossa. With its comparatively high formation, when both portions proceed in a common sheath, this division is observed somewhat higher.

In the popliteal fossa the tibial and common fibular nerves are located directly under the fascia. The tibial nerve descends almost vertically from the upper corner of the popliteal fossa to the lower and lies to the back and to the outside of the popliteal vein. Further, through the canalis cruropopliteus, it goes to the crus, where it is located in front of the deep fascial layer of the crus. At the top the tibial nerve lies on the posterior surface of the tibial muscle, and at the bottom -- in the sulcus between the long digital flexor and the long flexor of the big toe. Along almost the entire extent it is located to the outside of the posterior tibial arteries and veins. This explains the fact that during the Great Patriotic War, combined wounds to the tibial nerve and the posterior tibial artery occupied second place by frequency and, according to the materials for the development of illness histories, were observed in 8.0% of the cases. In the lower regions the tibial nerve is sometimes longitudinally split in the form of a loop 5-12 cm in length (L. P. Yakovleva). Behind the medial malleolus it divides into terminal branches -- the external and internal plantar nerve. Sometimes this division takes place at the level

of the apex of the medial malleolus, but often 1-3 cm below it.

The internal cutaneous nerve of the crus (n. cutaneus surae medialis) diverges from the tibial nerve in the popliteal fossa and usually proceeds in the form of a single trunk. Only in the lower third of the crus do branches diverge from it /253 and spread in the area of the external malleolus and the heel. At the level of the upper sections of the achilles tendon the internal cutaneous nerve of the crus penetrates the fascia and connects with the external, forming the sural nerve. The level of formation of the latter is extremely inconstant. Usually it begins at various portions of the lower third of the crus (fig. 106), more rarely at its middle. In rare cases this merging takes place in the popliteal fossa (fig. 107). Sometimes dual connections are observed between the external and internal cutaneous nerve of the crus. The terminal branches of the sural nerve spread in the skin and the subcutaneous fatty tissue of the external edge of the foot and the V toe. With high formation of the nerve it takes up an extensive zone also on the crus. Often in the central third of the latter there is overlapping coverage between the branches of the internal and external cutaneous nerve of the crus, as well as the internal cutaneous nerve of the lower extremity.

The internal plantar nerve is the thickest of the terminal branches of the tibial nerve. It gives muscular branches to the short digital flexor, to the muscle abducting the big toe, and to the short flexor of the latter, after which it separates into four branches. One of these goes along the inside of the plantar surface of the foot and the big toe, while the rest supply the facing edges of the I-II, II-III and III-IV toes. The first common digital nerve sends a branch to the first vermicular muscle, while the third is connected with the external plantar nerve.

The external plantar nerve gives branches to the quadrate muscle of the pelma and to the muscle abducting the V digit, and then separates into a deep and a superficial branch.

The deep branch supplies the interosteal muscles, the 2-4 vermicular, as well as the muscle adducting the big toe. Sometimes branches diverge from it to the external belly of the short flexor of the big toe. The superficial branch is divided into an internal and an external branch, which is located on the lateral, plantar surface of the foot in the region of the V and the inside of the IV digit. A splitting of the plantar nerve trunks is often observed.

The common fibular nerve in the popliteal fossa lies laterally, along the internal edge of the biceps muscle tendon, and then, intersecting the head of the fibula from the back, it passes to its neck. Here it is located superficially and is often injured with traumas to this area.

According to the materials for the development of illness histories, injuries to the fibular nerve with firearms bone fractures of the crus were observed in 47.8% of the cases, i.e. they comprised almost half of all the combined injuries of this nerve and the bone. In this area the nerve also adjoins the lower edge of the knee joint bursa, which also explains the combined injuries. At the neck of the fibula the nerve separates into the superficial and deep fibular nerves. In individual cases its division occurs below the indicated level (from 1 to 10 cm below the neck of the fibula).

Branches diverge from the trunk of the common fibular nerve to the knee joint bursa. [Also diverging here] is the external cutaneous nerve of the crus (n. cutaneus surae lateralis), which branches in the skin of the external surface of the crus. The

structure of the latter nerve is variable. In some cases branches diverge from the trunk in successive order, terminating at the level of the lower third of the crus. In other cases they diverge in fascicles primarily in the central third of the crus and above the external malleolus. In the upper third of the crus the external cutaneous nerve often gives off a rather large branch which supplies the skin of the posterior-external surface of the upper half of the crus. Penetrating the fascia at /254

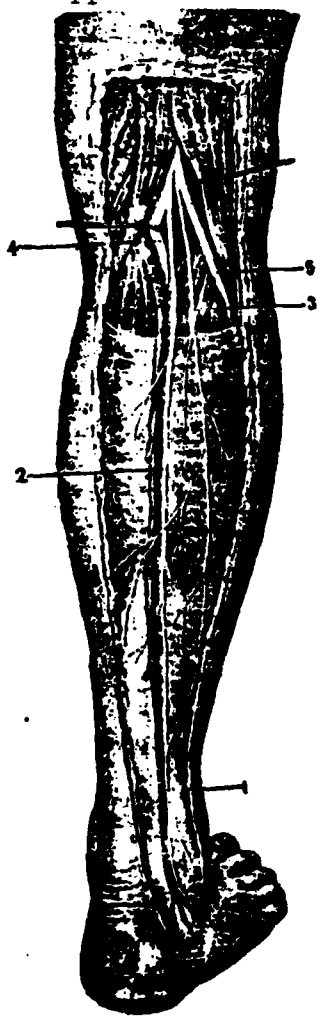


Fig. 106. Formation of the sural nerve in the lower third of the crus.

1 - sural nerve; 2 - internal cutaneous nerve of the crus; 3 - external cutaneous nerve of the crus; 4 - tibial nerve; 5 - fibular nerve.

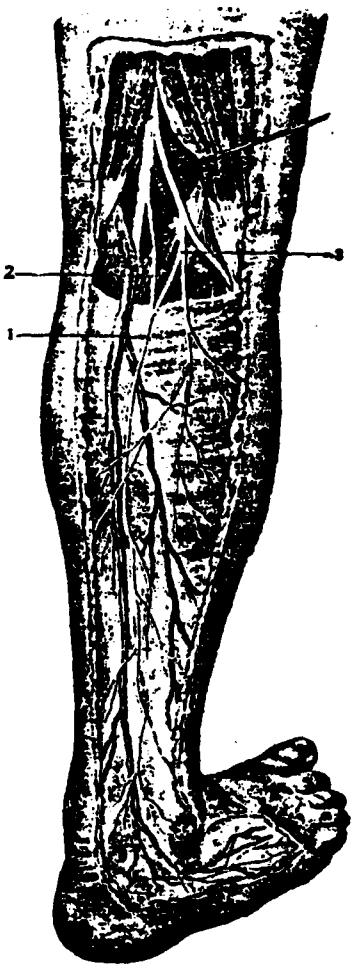


Fig. 107. Formation of the sural nerve in the popliteal fossa.

1 - sural nerve; 2 - internal cutaneous nerve of the crus; 3 - external cutaneous nerve of the crus.

various levels, this branch connects with the internal cutaneous nerve of the crus, forming together with it the sural nerve.

The deep fibular nerve penetrates the intermuscular septum and proceeds to the anterior muscle bed. It is located together with the anterior tibial vessels between the anterior tibial /255

Fig. 108. Innervation of the back of the foot by two nerves (according to Pasyukov).

1 - superficial fibular nerve; 2 - deep fibular nerve.

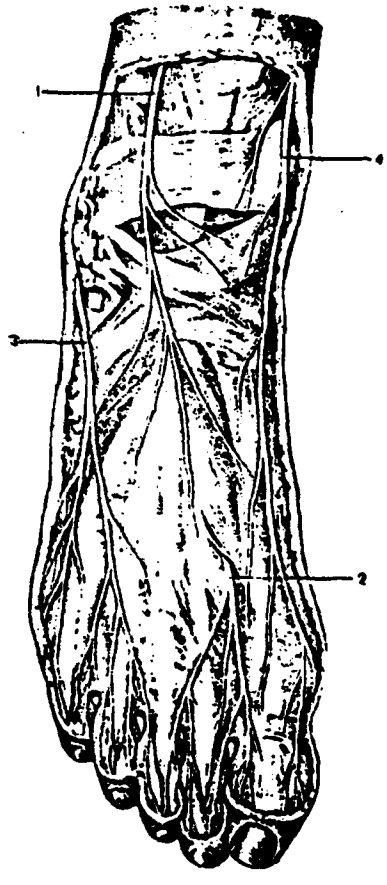


Fig. 109. Innervation of the back of the foot by four nerves (according to Pasyukov).

1 - superficial fibular nerve; 2 - deep fibular nerve; 3 - sural nerve; 4 - internal cutaneous nerve of the lower extremity.

muscle on one side (medially), the long digital flexor and the long flexor of the big toe on the other (laterally). In the upper half of the crus it lies to the outside of the vessels, then it intersects them, most often from the front, and in the lower half is located to the inside of them. On the crus it innervates all the muscles indicated above, and the terminal branches of this nerve spread to the facing surfaces of the I and II digits (fig. 108). In exceptionally rare cases it also supplies the adjoining surfaces of the II and III digits (fig. 109).

The superficial fibular nerve passes through the canalis musculo-peroneus superior and gives branches to the long and short fibular muscles. The exit level of this nerve into the /256 subcutaneous fatty tissue is rather constant and usually corresponds to the middle third of the crus (Ye. G. Lubenskiy, A. V. Pasyukov). Connections are observed with the internal cutaneous nerve of the lower extremity, with the sural and deep fibular nerves (fig. 109). In the lower half of the crus, the superficial fibular nerve separates into terminal branches -- the internal and the intermediate cutaneous dorsal nerves of the foot.

The cutaneous dorsal internal nerve is a continuation of the trunk of the superficial fibular nerve and on the back of the foot it separates into a lateral and medial branch. The latter supplies the skin of the internal surface of the foot and the big toe and in some cases the external surface of the big toe. This branch forms connections (most often dual) with the deep fibular nerve. Often they overlap each other. The lateral branch is directed to the second interdigital space and supplies the adjoining sides of the II and III digits. Sometimes it is absent.

The cutaneous dorsal intermediate nerve is directed to the third interdigital space, spreading to the facing surfaces of the III and IV digits. In cases of absence of an external branch of the cutaneous dorsal internal nerve of the foot, the cutaneous dorsal intermediate nerve supplies the area of the latter (Ye. G. Lubenskiy, A. V. Pasyukov).

The posterior cutaneous nerve of the thigh begins from the roots of the sacral plexus (most often the first - third) and leaves the pelvis through the foramen infrapiriforme. In the gluteal region it is located to the inside of the sciatic nerve and gives intermediate branches and cutaneous nerves to the gluteal region (nn. clunium inferiores). Coming out from under the edge of the gluteus maximus muscle, the posterior cutaneous nerve of the thigh lies under the broad fascia of the thigh, in the sulcus between the biceps muscle on the one side and the semimembranous and the semitendinous on the other. Numerous branches diverge from this nerve on the thigh which penetrate the fascia and spread in the skin and the subcutaneous fatty tissue of the posterior surface of the thigh. The terminal branches of the indicated nerve sometimes end at the crus and even reach the heel area.

## Methods of surgical approach to the individual nerve trunks of the lower extremity

Comparing the number of cases of nerve injuries to the upper and lower extremities, it should be noted that according to the materials for the development of illness histories, injuries to the upper extremities were noted in 61.0% of the cases, and to the lower -- in 38.3%. Simultaneous injuries to the upper and lower extremities were noted in 0.7% of the cases. Nerve injuries to the lower extremities were considerably more severe, usually keeping the patients bedridden for long periods. Pelvic

wounds with injuries to the sciatic nerve and its branches were particularly severe. Wounds to the nerves of the anterior surface of the thigh, the obturator and the femoral nerve were observed much more rarely.

The operative approach to the femoral nerve. As already indicated, the anatomical specifics of the femoral nerve are characterized by the insignificant extent on the thigh of its main trunk and by a large number of branches diverging from it (fig. 104 and 105). According to the materials for the development of illness histories, firearms injury of the femoral nerve was observed in 1.6% of the cases in relation to injuries to other nerves. The small percentage of injuries to the femoral nerve is explained by the fact that its trunk is very short and often, according to the data of anatomical studies, has a /257 high division under the Poupart's ligament (fig. 104). Also, combined injuries of this nerve and the major vessels were often terminal. Injury to the nerve in the pelvis with simultaneous injury to the pelvic vessels and the intestinal loops was noted in exceptionally rare cases, since most of the wounded with such combined injuries remained on the battlefield. However, surgical intervention on the femoral nerve was also performed for the purpose of reducing spastic contractions in the apparatus of the adductor muscles.

The cutaneous incision with access to the femoral nerve was performed differently, depending on the direction of the scars. However, the main cutaneous incision was made along the inside edge of the tailor's muscle. Its beginning was /258 2-3 cm below the anterior superior spine of the ilium and it extended for 10-12 cm with orientation toward the exposed internal edge of the tailor's muscle (fig. 110). Sharply retracting to the inside the opened fascial sheath, it is easy to find the femoral nerve at the internal edge of the iliopsoal muscle (fig. 111).

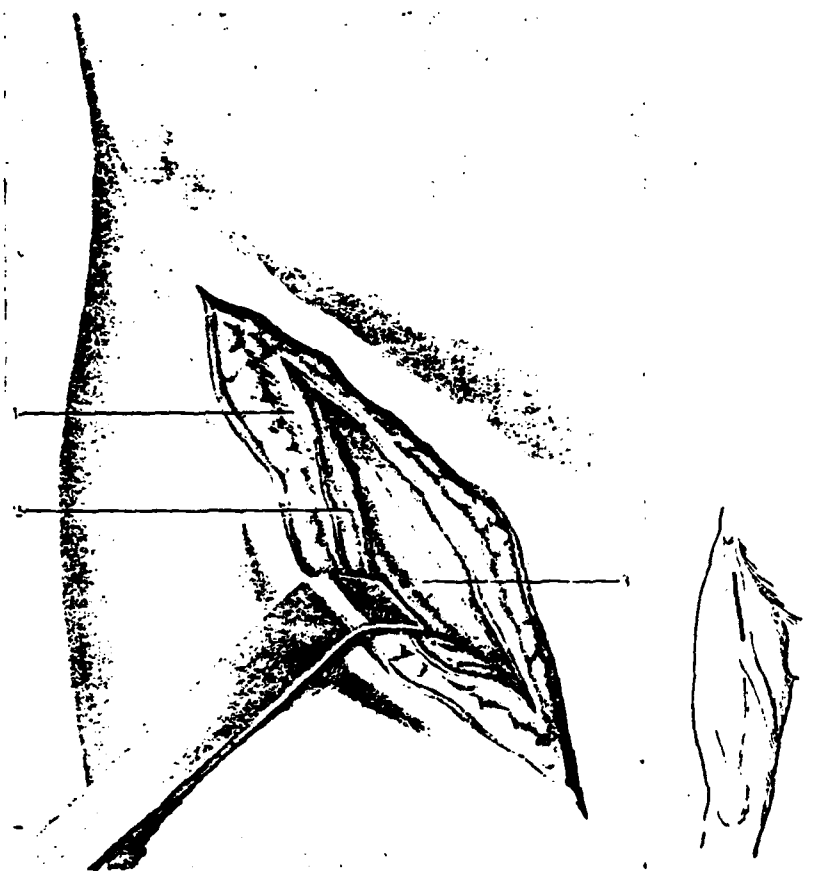

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Fig. 110. Approach to the femoral nerve. The direction of the cutaneous incision with extra-projectional approach. The skin, subcutaneous fatty tissue and fascia of the thigh are dissected, the tailor's muscle is retracted toward the outside. The dotted line shows the dissection of the deep fascia of the thigh.

1 - superficial layer of broad fascia of the thigh; 2 - tailor's muscle; 3 - deep layer of broad fascia of the thigh.

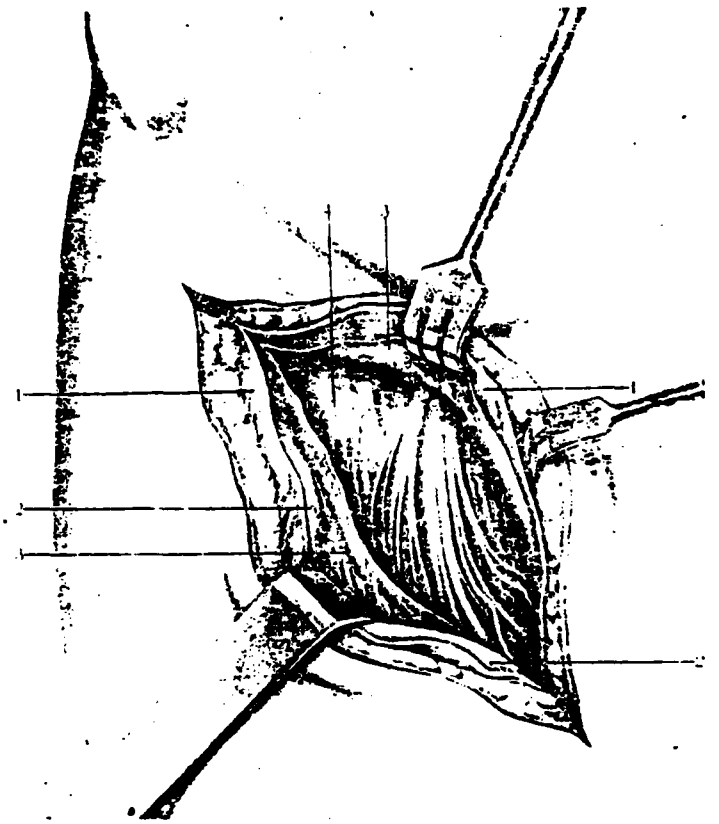

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Fig. 111. Approach to the femoral nerve. The deep fascia of the thigh is dissected.

1 - superficial layer of broad fascia of the thigh; 2 - tailor's muscle; 3 - deep layer of broad fascia of the thigh; 4 - iliopsoal muscle.

In cases of injury to the entire neurovascular fascicle, this roundabout way also turned out to be very convenient, and its continuation downward represents the classical approach to the femoral artery and vein and to the subcutaneous nerve of the crus in the Hunter's canal.

During neurolysis of the femoral nerve it is important to consider the fact that to the inside of it lie the femoral vessels. Moreover, a large number of its branches fan out and enter the flexor musculature of the thigh (fig. 111). The height and character of the injury may require suturing of the individual nerve branches to the main trunk. The coverage /259 of the nerve is done by the fibers of the iliopsoal muscle.

The operative approach to the obturator nerve. Restorative operations were rarely performed on this nerve, since its injury among the other nerves comprises an inconsequential percentage which was not considered. Operations were performed on it for the purpose of treating spastic contractures of the adducting musculature which were easily remedies by extra-pelvic intersection of the nerve. The latter operative interventions on the obturator nerve were performed more often during the war after firearms wounds.

The incision for access to the obturator nerve is made above the median long adductor muscle of the thigh. The fascia is sectioned away from this muscle to either side. Continuing the incision into the depth along the external edge of the long adductor muscle, the trunk of the obturator nerve is isolated in the fissure between it and the pectineal muscle. Here it separates into an anterior and a posterior branch (fig. 112).

The peripheral anterior branches run along the internal edge of the greater adductor muscle and are located near the external edge of the gracilis muscle. The posterior branch

goes down into the fissure between the short and greater adductor muscles. There are sufficient muscles here to cover the nerve. Often for better isolation of the nerve, particularly for preventing hemorrhaging from the obturator artery, it was necessary to resort to dissecting the pectineal muscle and subsequently suturing it.

The operative approach to the sciatic nerve in the gluteal region. Severe pelvic wounds were sometimes combined with injuries to the sacral and lumbar plexuses. Injuries to the gluteal region were primarily accompanied by injury either to the trunk of the sciatic nerve or to its individual component parts and, more often, to the fibular nerve. Wounds to the gluteal region were sometimes accompanied by hemorrhaging from the superior and inferior gluteal arteries. All these data, obtained from the study of materials of illness histories, conditioned the application of certain operative interventions, which is evident from table 24.

Table 24

The distribution of frequency of operative interventions with injury to the sciatic nerve depending on their character and times (in percentages)

| Character of the operations | Times of operations | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | 31.2 | 90.4 | 98.4 | 100.0 |
| Partial nerve resection... | 51.6 | 93.4 | 98.9 | -- |
| Total nerve resection..... | 34.0 | 85.1 | 98.6 | -- |
| Nerve resection without suture..... | 40.0 | 90.9 | 100.0 | -- |
| Total.... | 37.4 | 88.9 | 97.9 | 100.0 |

It follows from table 24 that partial resection of the sciatic nerve in the first 3 months after injury was performed in a little more than half the cases (51.6%), and by 6 months time -- in 93.4% of the cases. By 12 months, partial as well as complete resection of the sciatic nerve was performed in /260 almost all the cases. Neurolysis of the sciatic nerve was completed only by an elapsed period of 2 years. The explanation

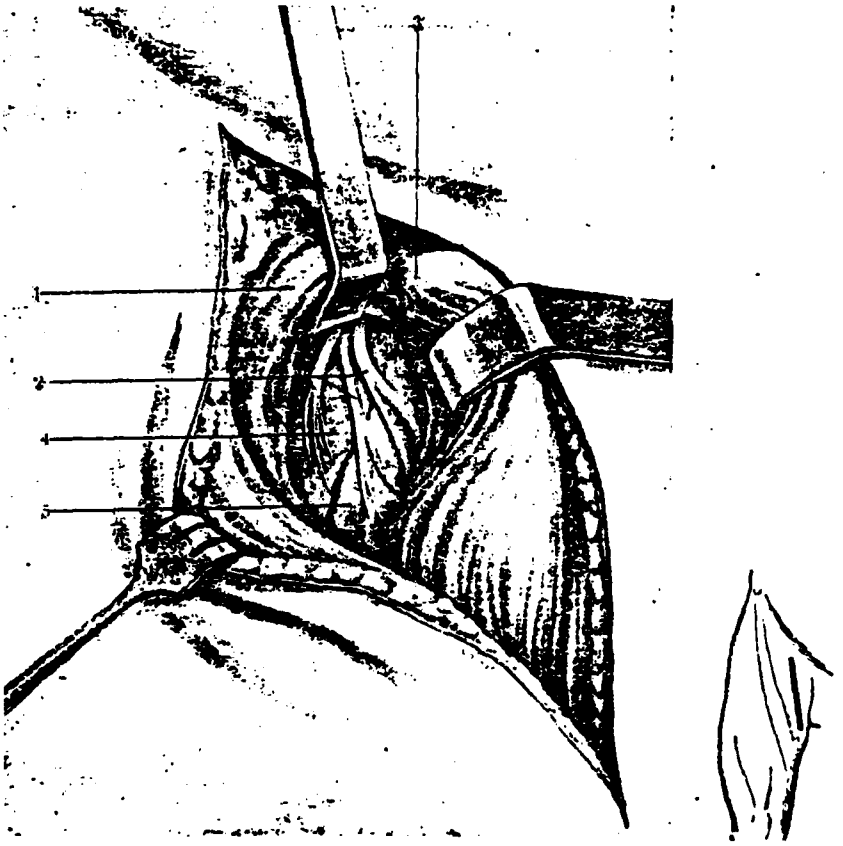

Fig. 112. Approach to the obturator nerve. The direction of the cutaneous incision with the extraprojectional approach. The skin, subcutaneous fatty tissue and fascia of the thigh are dissected.

1 - pectineal muscle; 2 - branches of the obturator nerve; 3 - long adductor muscle; 4 - external obturator muscle; 5 - short adductor muscle.

for this may be sought in the long-term regeneration of the sciatic nerve, particularly with its injury in the gluteal region. The performance of neurolysis in the early periods was also hindered by the presence of a large number of cases of firearms osteomyelytis which complicated the course of the wound process and necessitated the performance of the neurolysis at a later time.

The projectional line for the sciatic nerve in the gluteal region passes from the posterior-superior spine of the iliac bone to the external side of the ischial tuber.

To expose the sciatic nerve in the gluteal region, an /261 arc-shaped cutaneous incision with its concave surface to the outside was used. It began 2-3 cm below the posterior-superior spine of the iliac bone and was directed to the external part of the greater trochanter, further descending to the thigh (fig. 113). The linear incisions along the projections of the sciatic nerve dissected across the fibers of the gluteus maximus muscle.

With the arc-shaped incision, after the skin and subcutaneous fatty tissue are dissected, the dense fascia of the gluteal region is opened up somewhat to the inside of the cutaneous incision and the external-superior edge of the gluteus maximus is found. This edge is easy to find even before opening of the fascia, since the gluteus maximus muscle, covered with the standard muscular sheath, hangs down over the pearly dense fascia covering the median gluteal muscle. Penetrating into the fissure between these muscles, it is maximally retracted with hooks and, reaching the greater trochanter, a vertical incision is begun on the tendon, and then also on the muscular attachment of the gluteus maximus muscle.

If the nerve was injured near the sciatic opening or in the opening itself, there is no need to dissect the gluteus maximus muscle in the lower part of its attachment, since the peripheral part of the sciatic nerve is exposed by several centimeters without this.

The intersected or incised gluteal muscle is lifted and retracted to the back. Sometimes this manipulation was hindered due to the presence of a large number of scars located in the fatty tissue under the gluteus maximus muscle. A better method which facilitates the isolation of these scars is the introduction of 0.25% or 0.5% novocaine solution under the gluteus maximus muscle even in those cases when this operation is performed under cerebrospinal anesthesia or under narcosis. The internal part of the gluteus maximus muscle must be separated and retracted, which makes it possible to fully examine the piriform muscle and the sciatic nerve which comes out from under the edge of it (fig. 114). It should be kept in mind that in some cases the so-called high division of the sciatic nerve was observed, in which the fibular nerve exited either through the thickness of the piriform muscle or above it, while the tibial nerve passed under it.

With injury to the sciatic nerve immediately under the edge of the piriform muscle, it became necessary also to intersect this muscle near its tendinous attachment to the greater trochanter and to retract it backwards, as with the gluteal muscle. This made it possible to isolate the sciatic nerve almost to the very roots of the sacral plexus (N. A. Il'yina). The isolation of the sciatic nerve in this region must be done very carefully, since here it is easy to injure the trunk of the inferior gluteal artery and vein, whose damage causes considerable hemorrhaging which is difficult to stop (I. S. Kondrashov).

According to the materials of personal observations, in 2 cases there was found an upper limit of a sciatic nerve neuroma only after intersection of the piriform muscle. A 2% novocaine solution was introduced into the neuroma and it was sutured with thick silk thread. Pulling on this threat made it possible to mobilize and fully separate the central nerve segment from the scars. After excision of the neuroma, the nerve suture was performed with some difficulty in the ischiatic opening. After all the manipulations on the nerve were completed, sutures were applied to the piriform and the gluteus maximus muscles. Loop-shaped silk sutures were applied to the tendinous edges of the intersected gluteal muscle which held the muscle together with the fascia. The remaining parts of the gluteal muscle were sutured with thick catgut. Thus, the restored sciatic nerve /262 was covered with the undamaged part of the gluteal muscle.

With injury to the sciatic nerve in the lower portion of the gluteal region, the cutaneous incision had to be lengthened, adding a small vertical incision running along the back of the thigh to the semi-circular incision (fig. 113).

After dissection of the skin, the entire gluteal muscle was intersected hear the point of its attachment to the femur.

With access to the sciatic nerve in the upper third of the thigh, the incision was drawn either to the inside or to the outside of the nerve projection, depending on the direction and character of the scars (fig. 115). If the incision was drawn to the outside of the nerve projection, then after dissection of the skin the fascia was opened up to the outside and the external edge of the long head of the biceps muscle of the thigh was /263 exposed. The incision to the inside of the nerve projection is drawn in the opposide direction, isolating the same muscle edge. Continuing the incision into the depth and retracting the external edge of the long head of the thigh biceps muscle to the outside, the sciatic nerve is isolated (fig. 116).

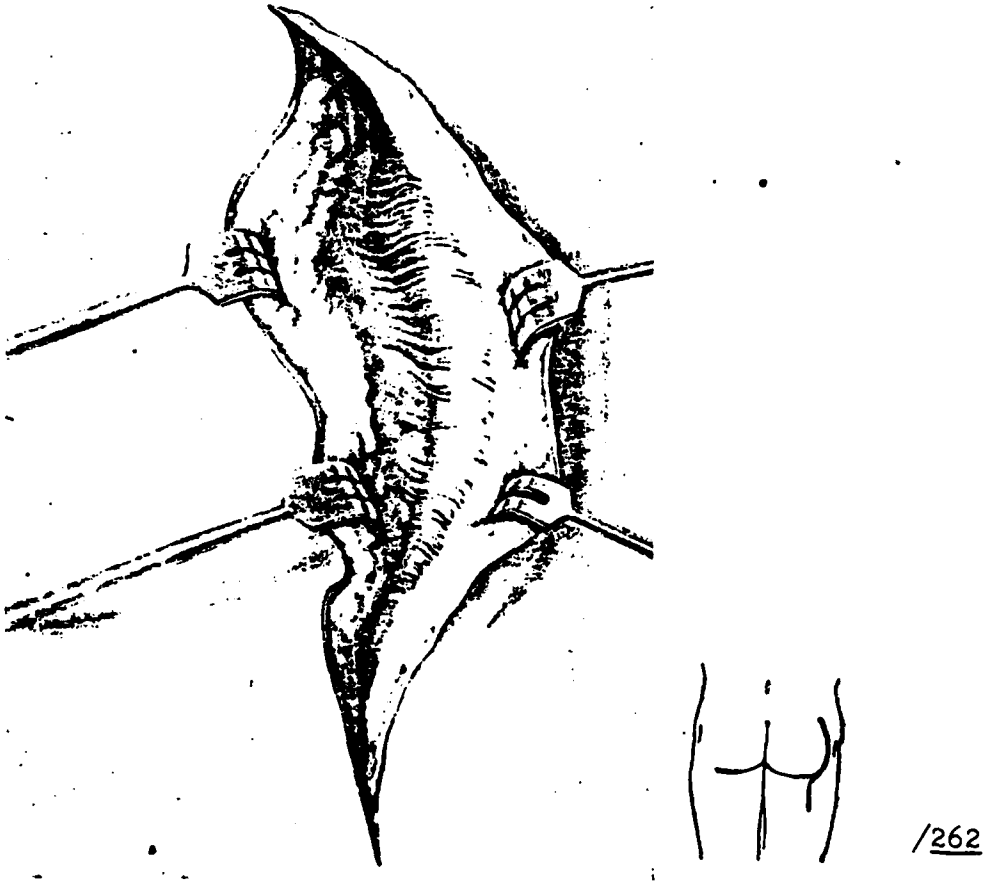

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Fig. 113. Approach to the sciatic nerve in the gluteal region. The direction of the extra-projectional cutaneous incision. The skin and thick layer of fatty tissue included in the superficial fascia are dissected.

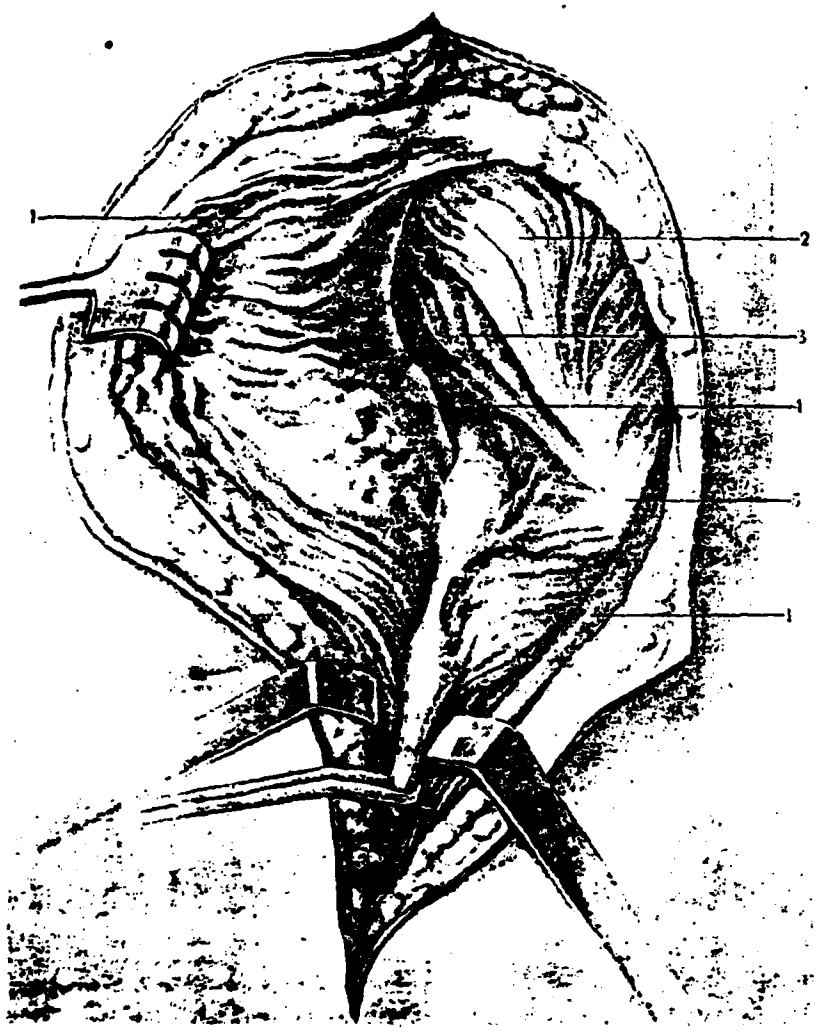


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Fig. 114. Approach to the sciatic nerve in the gluteal region. The gluteus maximus muscle is cut away and retracted to the inside.

1 - gluteus maximus muscle; 2 - median gluteal muscle; piriform muscle; 4 - subpiriform opening; 5 - greater trochanter of the thigh.

Coverage of the operated nerve is provided by suturing /264 the long head of the biceps muscle with the lower edge of the gluteal.

The operative approach to the sciatic nerve in the center of the thigh was performed either to the inside or to the outside of the nerve projection, depending on the scars. If a transverse

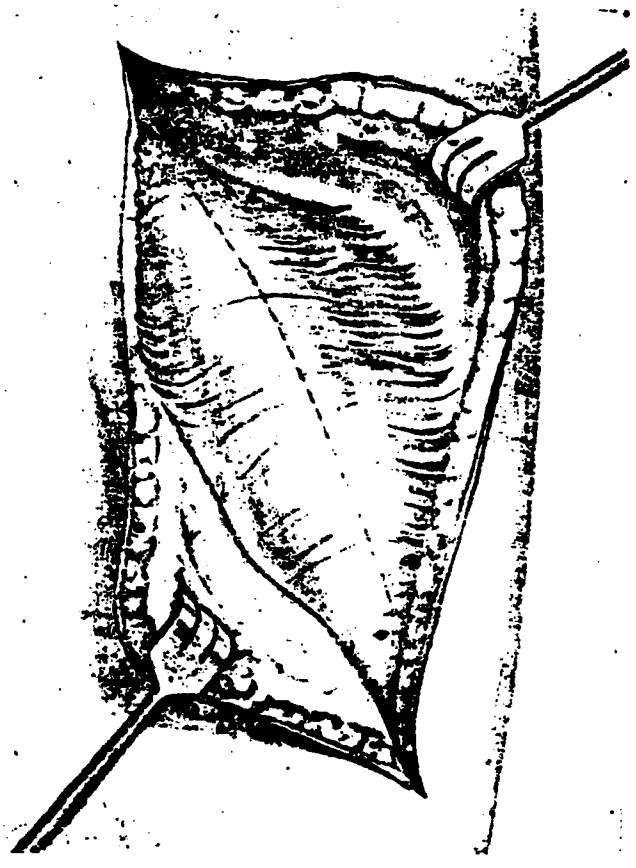


Fig. 115. Approach to the sciatic nerve in the upper third of the thigh. The direction of the cutaneous incisions with the extraprojectional approach: two longitudinal incisions extending outside the nerve projection are added to the transverse incision which excises the scar. The dissected skin and subcutaneous fatty tissue are retracted to the sides.

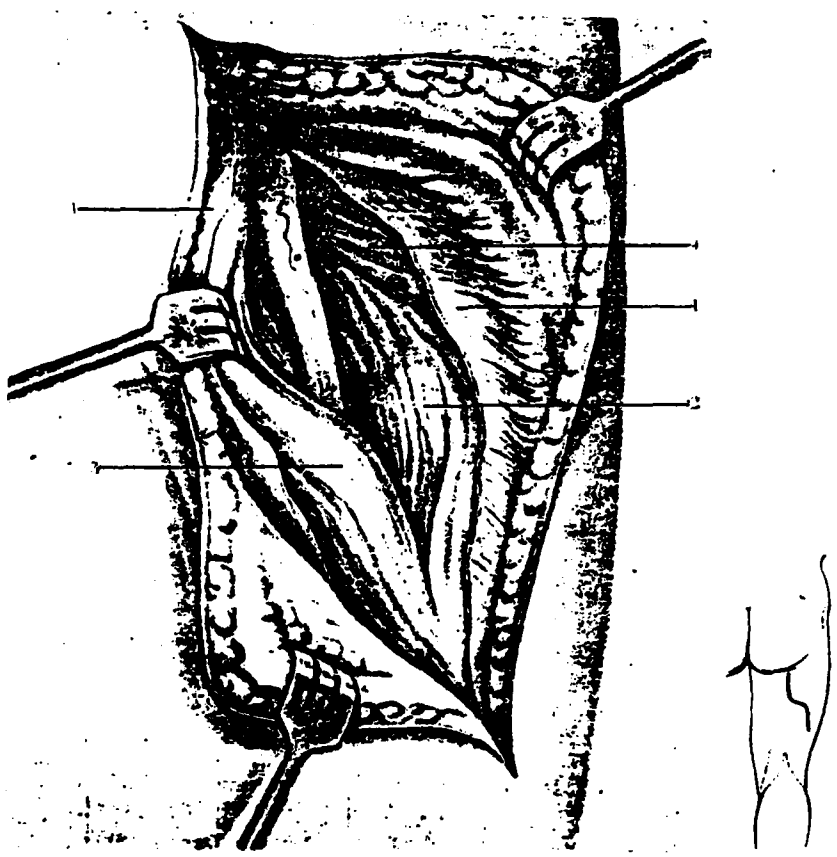
scar is present, two incisions should be added to it, of which one must run to the outside and the other to the inside of the nerve projection. After separating the skin together with the subcutaneous fatty tissue, the fascia is opened either over the semitendinous muscle (to the inside of the projection) or at the biceps muscle of the thigh (to the outside of the projection). In both cases after cutting the fascia, the muscular fissure, between the biceps muscle of the thigh on one side and the semitendinous and semiperistic muscle on the other side, is found /265 The projectional incision is drawn orienting along this fissure. Retracting the fissure with hooks and penetrating into the depth, the sciatic nerve is isolated. In excising deep scars and isolating the nerve in this region, strong hemorrhaging is often noted from the penetrating branches of the deep femoral artery. The hemorrhaging is stopped by ligations and gauze pads soaked in hot physiological solution. Electrocoagulation has recently been successfully used for this purpose. The bed and wrapping of the nerve were usually produced from the muscles between which the nerve was found.

It should be noted that of the cutaneous nerves, the posterior cutaneous nerve of the thigh may be injured here. It is located strictly under the midline and lies directly under the fascia of the thigh. Therefore, in performing the fascial incision /266 along the posterior side of the thigh, it is necessary to notice also any possibility of injuring the posterior cutaneous nerve of the thigh.

Patient G., who had an ulceration which would not heal in the upper third of the posterior surface of the thigh, experienced very acute soreness immediately above the ulceration. Injury to the posterior cutaneous nerve of the thigh had been presumed. The diagnosis was confirmed during the operation. The nerve was thorough isolated, the neuroma was excised and two

sutures were applied, which restored the integrity of the nerve trunk. The ulceration was also excised. The skin, fascia, and muscles could be sutured after excision of the scars by using an additional incision which eased the tension on the skin.

The pains ceased in the post-operative period and the ulceration did not recur.



/265

Fig. 116. Approach to the sciatic nerve in the upper third of the thigh. The fascia of the thigh is opened and the sciatic nerve exposed.

1 - fascia of the thigh; 2 - greater adductor muscle; 3 - long head of the biceps muscle of the thigh; 4 - lesser adductor muscle.

The operative approach in the popliteal fossa to the branches of the sciatic nerve -- the tibial and the fibular nerves. In /266 the upper corner of the popliteal fossa, the sciatic nerve separates into the tibial and the fibular nerves (fig. 106 and 107). The projection of the tibial nerve passes from the upper corner of the popliteal fossa to the center of the distance between the internal malleolus of the tibia and the achilles tendon. The projection of the fibular nerve runs from the same upper point of the popliteal fossa to the head of the fibula.

The operative approach to the tibial nerve. Injuries to the tibial nerve were most often observed in the popliteal fossa. Here the nerve is covered only by skin, fascia, and a thin layer of fatty tissue. Injuries to the tibial nerve in this region were often combined with firearms fractures of the bones composing the knee joint. In the upper and middle third of the crus, the tibial nerve was rarely injured, since here it is covered by thick muscle masses.

Data on the frequency of surgical interventions on the tibial nerve are presented in table 25.

Table 25

Distribution of the frequency of operative interventions with injury to the tibial nerve depending on their character and times (in percentages)

| Character of operations | Time of operations | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | -- | 80.0 | 100.0 | -- |
| Partial nerve resection.. | 50.0 | 100.0 | -- | -- |
| Total nerve resection.... | 40.0 | 80.0 | 100.0 | -- |
| Total..... | 21.1 | 89.5 | 100.0 | -- |

From this table it is evident that neurolysis of the tibial nerve was put off for a comparatively long time -- up to 6 months, evidently in connection with the large number of combined bone injuries. Complication of the latter by osteomyelitis required comparatively long periods for healing, after which it was possible to perform operations on the nerve. Partial resection was performed at early periods: by 3 months time -- in 50% and by 6 months -- in all cases.

The projectional operative route for the approach to the /267 tibial nerve runs along the center of the popliteal fossa rhombus. The exposure of the nerve does not present any difficulties, since the nerve is covered only with skin, fascia of the popliteal fossa, and a very thin layer of fatty tissue. The inferior subcutaneous vein of the thigh may be encountered along the way (v. saphena parva). The unsoundness of the projectional method of operative approach is manifested with particular clarity in this region. In the post-operative period, a scar is formed directly over the nerve. The surgeon is placed in a particularly hopeless situation when he is forced to replace a large nerve defect with the aid of the transplant method or by anastomosis (see fig. 139).

With isolated injury of the tibial nerve, the cutaneous incision should be drawn significantly to the inside of the nerve projection with mandatory location of the incision 2-3 cm above and below the limits of the popliteal fossa. When the skin is retracted backward, the fascia is opened. Moving back the latter, the tibial nerve is sought orienting by the inferior subcutaneous vein of the crus. The vein is moved aside, the fatty tissue is dissected along the midline, and the tibial nerve is exposed. In freeing it from the scars, it was necessary in almost all cases to expose the point of division of the sciatic nerve, since the absence of muscular coverage in the

popliteal fossa often conditioned the formation of large defects in the nerve trunk as a result of firearms wounds. For the same reasons it was necessary to expose the tibial nerve distally of the popliteal fossa, moving aside the internal edges of the gastrocnemius muscle. By separating the heads of the latter it is possible to significantly increase the ability to examine the peripheral segment.

The sutured nerve in the center of the popliteal fossa cannot be covered with muscles. Its coverage is accomplished by a layer of fatty tissue sutured with very thin catgut. The suturing of the popliteal fossa fascia is done with thin silk outside the nerve projection.

The operative approach to the tibial nerve on the back of the crus in its upper third is performed by a vertical cutaneous incision running from the posterior surface of the internal condyle of the femur along the extent of the entire upper third of the crus. Upon dissection, the skin is retracted to the back and the fascia is opened. Pulling back the fascia to the outside, the internal head of the gastrocnemius muscle is isolated and intersected, and the latter is retracted to the back. This exposes the entire neurovascular fascicle located between the gastrocnemius muscle and the tendinous arch of the soleus muscle (fig. 117).

The full functional value of the gastrocnemius muscle is easily restored by suturing, and the nerve subjected to operative intervention is covered with immobile muscle belly.

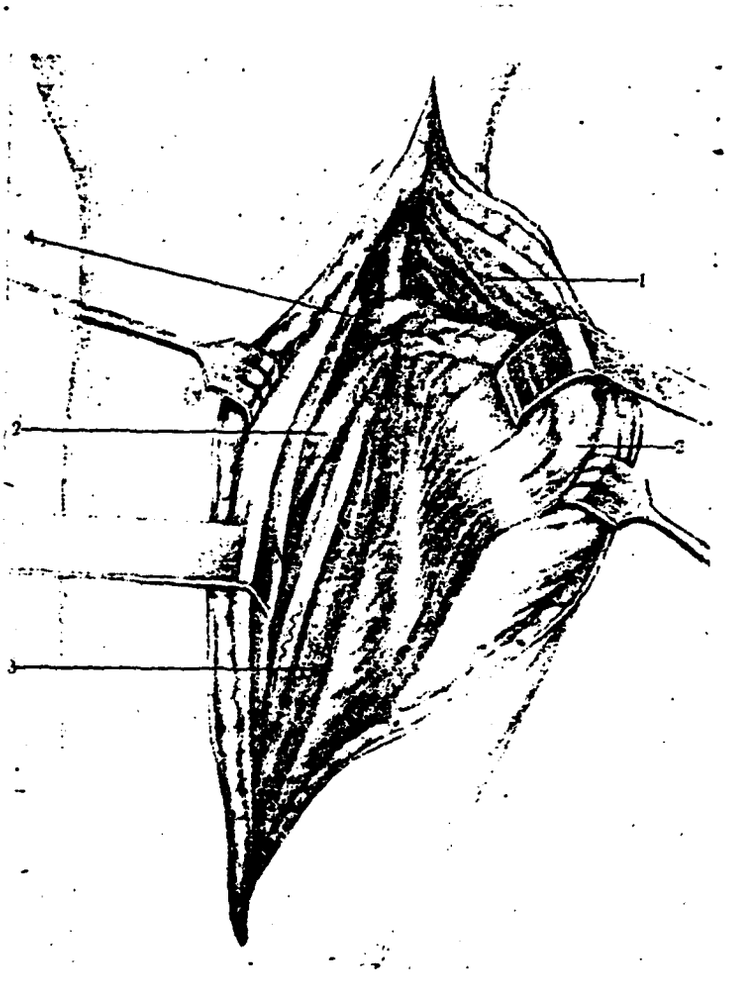
The approach to the tibial nerve in the middle third of the crus is achieved by the same cutaneous incision described above, prolonged vertically downward and passing near the internal edge of the tibia. After dissecting the skin, the fascia is opened and the internal edge of the gastrocnemius

muscle is exposed. The latter is retracted backward. The soleus muscle which is found at the bottom of the wound is separated from the bone and also retracted backward. Upon dissecting the fascia of the deep muscle bed, the tibial nerve is exposed along with the posterior tibial artery.

For restorative operations on the nerve, particularly with its major defects, such an approach is insufficient. In approaching the upper third of the crus, it is necessary to dissect the attachment of the internal head of the gastrocnemius muscle and, separating the soleus muscle from the bone, disrupt the integrity of its tendinous end (fig. 117 and 118). After performing the operative interventions on the nerve, the integrity of the gastrocnemius and the soleus muscles is restored. /268

In operative access to the tibial nerve in the region of the internal malleolus it is necessary to perform the cutaneous incision along the internal edge of the achilles tendon. Retracting the skin to the front, the fascia is opened above the flexor of the big toe and, retracting the latter also to the front, the tibial nerve is exposed.

Depending on the location of the scars, the incision may run forward from the projection of the tibial nerve. In these cases the cutaneous incision in made immediately behind the internal condyle. The skin is also retracted to the back, the fascia is opened above the long digital flexor and, directing the incision still more to the back, the neurovascular fascicle is found. The tibial nerve lies behind the artery. In the presence of a transverse or oblique scar, one part of the incision is located to the front, the other -- to the back of the nerve projection. Muscular coverage of the nerve here is possible only in the upper part of the wound. This is why the extraprojectional method of approach to the nerve trunk is particularly necessary. /269 /270




/268

Fig. 117. Approach to the tibial nerve in the upper third of the crus. The skin, subcutaneous fatty tissue and fascia of the crus are dissected along the extraprojectional method. The gastrocnemius muscle is bluntly moved back, the internal head of the soleus muscle is dissected and moved aside.

1 - gastrocnemius muscle; 2 - soleus muscle; 3 - long flexor of the thumb; 4 - tendinous ring of the soleus muscle.

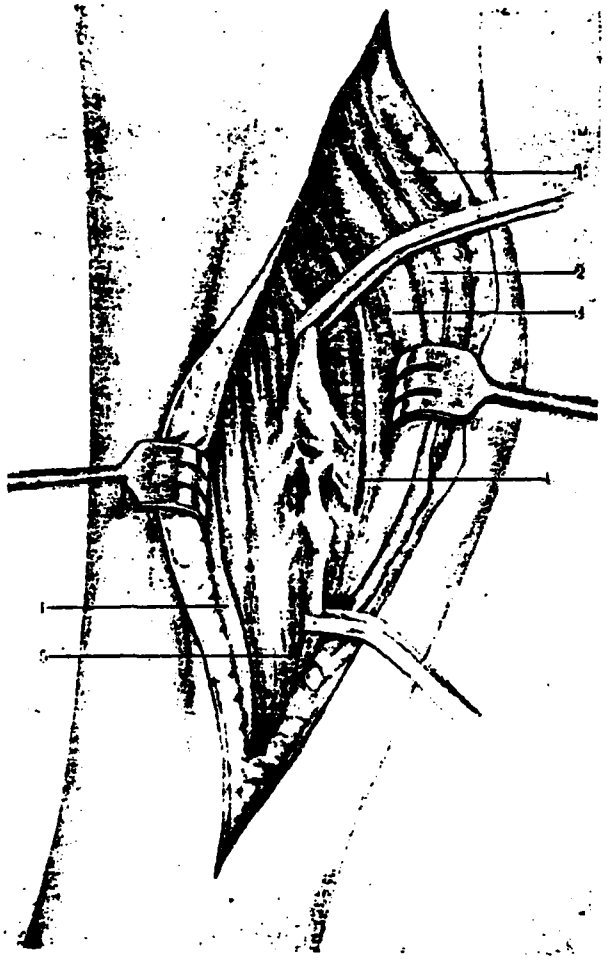


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Fig. 118. Approach to the tibial nerve in the central third of the crus: the skin, subcutaneous fatty tissue of the crus are dissected according to the extraprojectional method. The gastrocnemius and soleus muscle are separated and retracted to the inside.

1 - fascia of the crus; 2 - gastrocnemius muscle; 3 - soleus muscle; 4 - fascia separating the superficial muscle bed from the deep; 5 - common long digital extensor.

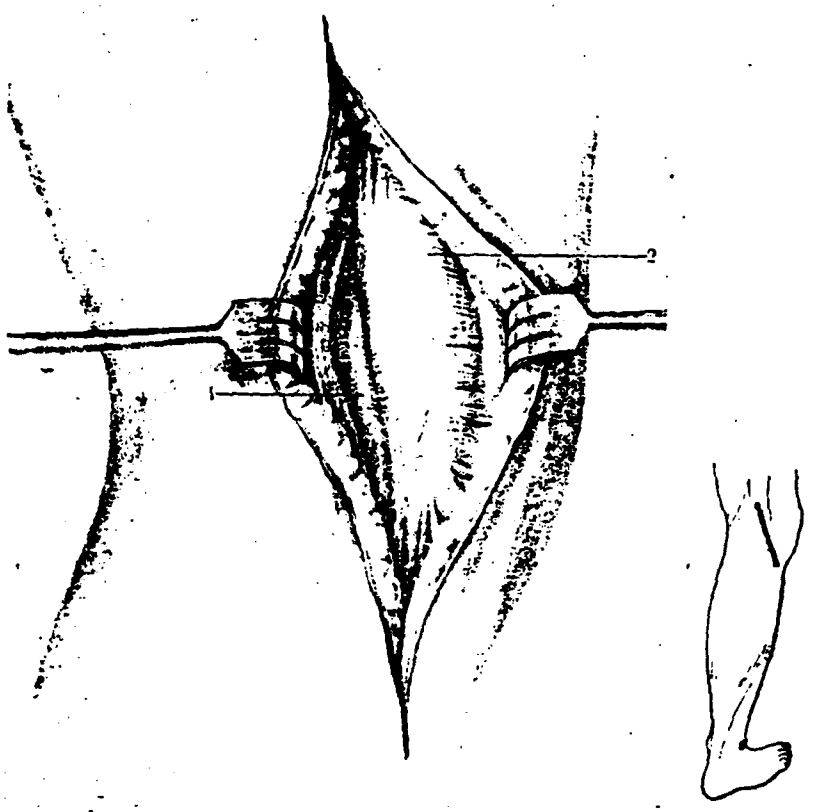

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Fig. 119. Approach to the fibular nerve in the popliteal fossa. The direction of the cutaneous incision. The skin is dissected together with the subcutaneous fatty tissue to the aponeurosis.

1 - fascia of the popliteal fossa; 2 - tendon of biceps muscle of the thigh in its fascial sheath.

The approach to the fibular nerve in the lower part of the popliteal fossa is created by a cutaneous incision drawn above the tendon of the biceps muscle of the thigh up to the point

where this muscle attaches to the head of the fibula (fig. 119). To the inside of the cutaneous incision, the muscle fascia is opened up, and even more to the inside the internal edge of the tendon to the thigh biceps muscle is exposed. Continuing the incision into the depth and bluntly separating the fatty tissue, the fibular nerve is found (fig. 120). It must also often be isolated from the point of division of the sciatic nerve to the neck of the fibula.

This method of approach provides for the subsequent partial/271 muscular, complete fatty tissue, fascial and cutaneous extra-projectional coverage which protects the nerve against subsequent cicatrical compression.

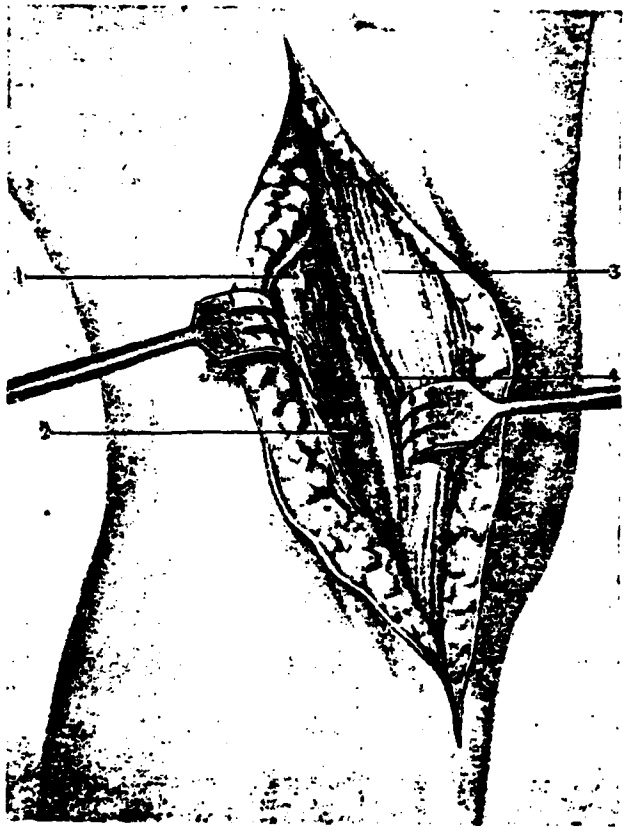



Fig. 120. Approach to the fibular nerve in the popliteal fossa. The fascia of the biceps muscle and the popliteal fossa is opened.

1 - fascia of the popliteal fossa; 2 - fatty tissue; 3 - biceps muscle; 4 - common fibular nerve.

Simultaneous operative approach to the tibial and fibular nerves. Sometimes it is necessary to expose both nerves simultaneously (most often with large transverse scars). The cutaneous incisions run from the ends of the excised scar outside the projection of both nerve trunks.

In these cases, drawing a longitudinal incision across the center of the popliteal fossa turns the surface of the latter into a cross-shaped scar which compresses the nerve trunks in all directions. The cutaneous incision should be drawn between the projections of both nerves (see fig. 139). After the skin is dissected, the fascia is opened up and re- /272 tracted to the outside to isolate the fibular nerve. When the fascia is retracted to the inside, the fibular nerve is exposed. The operation on each of the nerves and the subsequent restoration of the tissue in no way differ from the methods described above.

The operative approach to the fibular nerve. Injuries to the fibular nerve were characterized by frequent combined injuries with the bones and primarily with the fibula. The injury to this nerve was most frequent in the area of the popliteal fossa and the upper third of the crus.

Presented below are the data on the frequency of operative interventions on the fibular nerve (table 26).

Table 26

Distribution of the frequency of operative interventions with injury to the fibular nerve depending on their character and times (in percentages)

| Character of operation | Time of operation | | | |
|---|---|---|---|---|
| | up to 3 months | up to 6 months | up to 12 months | up to 2 years |
| Neurolysis..... | 18.5 | 92.6 | 100.0 | -- |
| Partial nerve resection | 40.0 | 100.0 | -- | -- |
| Total nerve resection.... | 37.0 | 96.3 | 100.0 | -- |
| Orthopedic corrective surgery..... | 33.3 | -- | 100.0 | -- |
| Total.. | 29.0 | 89.3 | 100.0 | -- |

It is evident from table 26 that neurolysis of the fibular nerve was used at comparatively late times: only 18.5% of the wounded were operated within a period of up to 3 months, while most of the neurolysis operations were performed within a time period of from 3 to 6 months. The explanation for this should be sought in the large number of combined bone injuries. Nerve resection -- partial and complete -- was performed in 40.0% of the cases by 3 months time, and by 6 months it was performed in all cases.

In evaluating operations performed on this nerve, it is necessary to note the comparatively high number of orthopedic corrective operations which often corrected pathological conditions of the extremity in shorter periods of time.

With the operative approach to the fibular nerve in the upper third of the crus, a straight cutaneous incision was made from the lower part of the easily palpable tendon of the biceps muscle of the thigh to the projection of the belly of the common digital extensor. Upon dissection, the skin is moved to the back and the fascia opened above the tendon of the biceps muscle at its point of attachment and above the beginning of the common digital extensor belly (fig. 121). To the back of the tendon of the thigh biceps muscle, the fibular nerve is exposed. In the depth of the sulcus between the common digital extensor and the long fibular muscle, numerous branches of the fibular nerve are isolated on the fibula. Isolating the external edge of the long fibular muscle, it is possible to see the fibular nerve to the beginning of its division into branches (fig. 121).

Near the neck of the fibula the fibular nerve is located so superficially that its exposure along the projection at this point should not be done under any circumstances, since it is /273 impossible to cover the nerve with muscles.

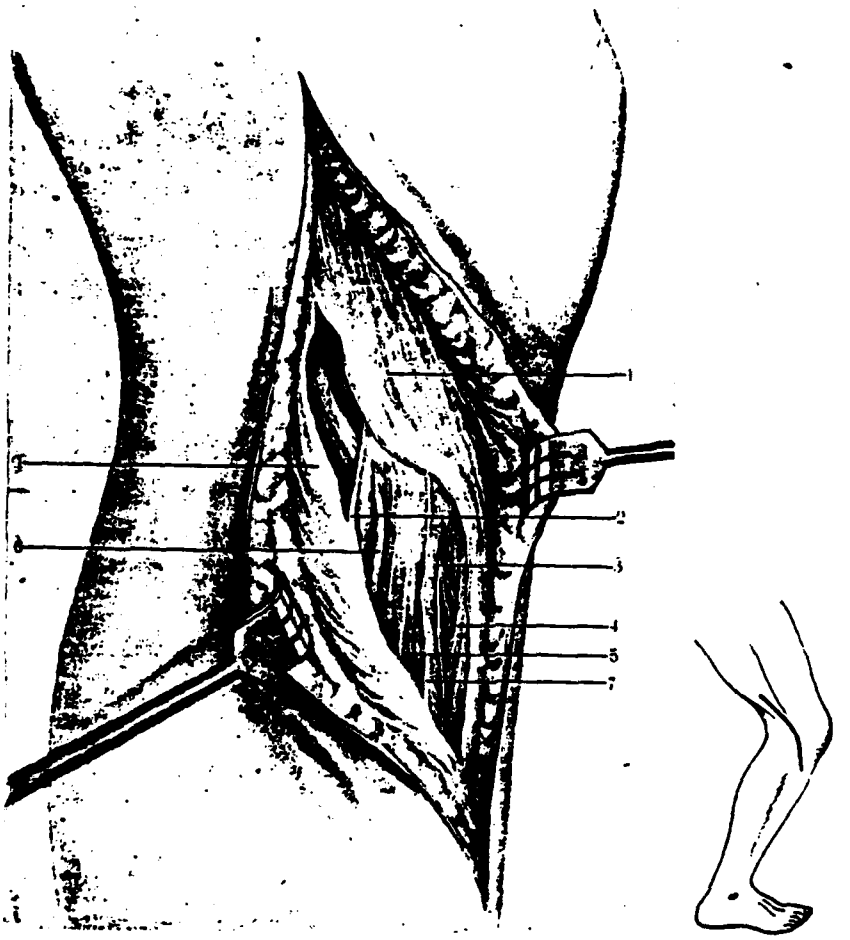


Fig. 121. Approach to the common fibular nerve and its branches in the upper third of the crus. The direction of the cutaneous incision with the extraprojectional approach. The skin is dissected along with the subcutaneous fatty tissue. Aponeurosis of the anterior and lateral bed of the crus in the upper third.

1 - crus aponeurosis; 2 - external septum of the

Fig. 121 (cont'd).

fibular muscle bed; 3 - deep fibular nerve; 4 - anterior tibial muscle; 5 - long fibular muscle; 6 - superficial fibular nerve; 7 - septum between the anterior and lateral bed.

The superficial fibular nerve may be exposed by continuing the preceding cutaneous incision above the belly of the common digital extensor. The fascia should be dissected at the external edge of this muscle. Retracting the long fibular muscle to the outside, it is easy to isolate the formation being sought (fig. 121).

The deep fibular nerve is exposed from the same cutaneous /274 incision, but the fascia is opened at the internal edge of the anterior fibular muscle and the nerve is found on the very interosteal septum together with the anterior fibular artery (fig. 121).

## The methodology and technique of operations performed on the injured peripheral nerve

During the period of the Great Patriotic War, a number of questions relating to the methodology and technique of nerve operations received new solution.

The maximal number of operations was performed with a healed, more rarely with a healing wound. The inflammatory process in a nerve involved into the scar caused the most varied symptoms of affliction conditioned by the irritation of the trunk, its compression, partial disruption in conductivity or complete physiological or anatomical severance. Preliminary diagnosis could determine the character of the injury only to a certain degree. The basic decisive measure not only of a treatment, but primarily also of a diagnostic character was the operation.

During the Great Patriotic war, the overwhelming majority of operations on the peripheral nerve began with neurolysis -- a method requiring a great deal of skill and tact on the part of the surgeon (N. N. Burdenko). This was explained by the fact that often even on the operating table, using electro-diagnostic devices, it was impossible to immediately decide the question of the necessity for resectioning the injured area with subsequent suture application.

An analysis of the materials shows that most operations on the peripheral nerve were preceded by conservative treatment using various methods. Among the conservative and prophylactic methods is primarily splinting, massage, baths, electrization, careful application of mud and paraffin treatment, sollux, ultraviolet radiation, etc.

Performed as preparatory operative interventions were the removal of foreign bodies, the treatment of osteomyelitis, plastic closure of skin defects, operations performed on the vessels in the presence of an aneurism, plastic surgery on the bones, muscles, tendons, and finally operations performed on the vegetative nervous system. The latter intervention was performed most often after the operations on the peripheral nerves. However, in a number of cases it preceded them, specifically in the case of simultaneous severe trauma to the vessels (B. G. Yegorov, N. I. Makhov, M. A. Nikitin and others), with unhealing ulcers and edema (A. N. Bakulev, B. G. Yegorov, V. V. Lebedenko, M. A. Nikitin, G. A. Rikhter).

With sharp pains arising after injuries to the peripheral nerves, some neurosurgeons began with operations performed on the vegetative nervous system (A. V. Bondarchuk, F. M. Lampert, M. A. Nikitin and others).

By the time the wound healed fully, the diagnosis of nerve injury had usually been clarified. It became particularly apparent with the onset of atrophy to a group of muscles.

Numerous indicators of nerve compression, often characterized by sharp pains, hyperesthesia, sometimes partial muscular atrophy, all dictated the necessity of preliminary application of neurolysis. X-rays of the extremity were usually considered necessary to clarify the presence of foreign bodies located /275 near the nerve and usually being the cause of the pressure on the nerve trunk. Aside from the presence of fragments, bullets, bone sequesters, in later periods it was primarily necessary also to consider the significance of the strong development of connective tissue, which mechanically compressed the nerve. However, the actual inflammatory process leading to the development of connective tissue already disrupted the conductivity of the nerve trunk in the initial periods (S. P. Protopopov). The organization of connective tissue between the muscle fascicles led to the formation of thick cicatrical tissue which sharply disrupted the vascularization of not only the muscles, but the nerves as well.

When a main nerve trunk was injured, as indicated above, there was often simultaneous injury also to the parallel vessels -- the arteries and veins.

According to the materials for the development of illness histories, simultaneous injury to the vessels and nerves was observed in 5.4% of the cases, while injury to the nerves together with bone fractures -- in 45.2% of the cases.

With these combined injuries, a unique picture of nerve trunk compression by bone fragments and by nerve inclusion into the bone callous was created. The nerve trauma hindered the regeneration of the bone fracture.

If the injury to the nerves was complicated by osteomyelitis, then in the process the nerve trunk was involved, partly in the form of neuritis.

## The general methodology of isolating the nerve from scars (neurolysis)

The neurolysis operation was performed with anesthesia of the tissues under the scar. It was firmly established that cutaneous scars which did not contain underlying subcutaneous fatty tissue must be excised. If they were allowed to remain, as a rule, they led to necrosis with subsequent suppuration, often involving the entire wound and the nerve trunk.

Upon dissection of the skin and excision of the cutaneous scar, additional anesthesia of the wound edges and its deep sections was practiced. This was followed by a thorough isolation of all the tissues surrounding the nerve. This was necessary for the subsequent by-layer anatomical restoration of the tissues.

The methodical separation of the tissues surrounding the nerve made it possible to have good orientation in the center of the injury.

Here it should be noted that in separating the muscles, only blunt forceps should be used, and then very carefully.

The operative approach to the nerve must be planned and exceptionally sparing. Muscles should not be separated by tearing apart their fissures of their tissue. It is necessary to protect the muscles against excess trauma. The best method of separating muscles should be considered the sharp method (with a scalpel or scissors). The muscles should be separated from the scar going step by step within the limits of their boundary with the scar. Novocaine infiltration is useful in such operations, even if the operation is being performed under general narcosis.

The nerve must be isolated within the limits of healthy

tissue. It is never recommended to go directly toward the scar or an easily palpable neuroma. The circular painful scar composed of muscles and fascia may appear to be a neuroma, while in dense thick scars which develop after extensive suppuration, it is impossible to isolate the nerve without damaging it. Therefore, the well-known position which was confirmed during the Great Patriotic War should be taken as a rule, specifically: surgery of nerve trunks which is based on extensive and /276 precise anatomical knowledge leads to better results. In isolating a nerve, elevators, blunt hooks, scissors or even hemostatic forceps should not be used in the intermuscular fissures.

Having located the nerve between the muscles, it is necessary to separate the muscles in such a way that the nerve trunk is adequately visible. Within the limits of healthy tissue, the nerve is usually clearly visible even through the thin fascial neurovascular sheath. This sheath should be used: for preliminary anesthesia and location of the nerve, novocaine is injected into the paraneural fatty tissue with a thin needle. This makes it possible to see the nerve in the surrounding thin fascial bed. Incising the bed with the end of a sharp scalpel, the nerve is carefully displaced with a moist gauze compress, and better with a cotton tampon , and then a blunt, slightly bent elevator is lightly slipped under the nerve. This should be done very gently and carefully. N. N. Burdenko notes that moving healthy nerve trunks with forceps in a wound while looking for the point of its injury led in the post-operative period to muscle paresis in the region of the nerve innervation. A gauze strip should usually be placed under the nerve trunk which is being held on the elevator. This strip should not be too narrow, since a narrow strip takes on the form of a tourniquet and, obviously, may traumatize the nerve trunk. A strip of soft glove rubber may also be used for this purpose.

The strip should be inserted either with tweezers or with a special needle of the Deshamp type with an expanded opening. The strip should be removed from the Deshamp needle under the protection of the elevator so that the gauze is not pulled over the edge of the nerve and so that the rubber does not snap against the nerve trunk. The central and peripheral ends of the nerve which are held within the limits of the healthy tissue represent the starting points for continuing the operative intervention. Once again novocaine is introduced under the nerve and under its surrounding scars from the peripheral ends in the direction of the central segments. Novocaine is also injected again under the epineurium.

As a result of the specific reaction of the tissues to the introduced liquid, the nerve usually begins to stand out well in its surrounding scars. If large portions of liquid are introduced under the nerve, the nerve trunk will stand out above the scar tissue.

If the scars are very thick, then the operation should be begun with incision of the scar near the nerve and sectioning should be done in small longitudinal sections, all the while holding the dense scar tissue with tweezers. The nerve cannot be held with tweezers, it must be held with a moist cotton ball. Usually, however, it is fully sufficient to carefully tighten the nerve on the holders, which is usually done by the assistant. If when the nerve is tightened organized thick bands stand out along its posterior surface, they are usually grasped with hemostatic forceps and cut off with scissors at the edge of the muscle. Then, holding on to the hemostatic forceps, the scar is separated from the nerve trunk.

When performing the neurolysis, it is necessary to preserve the epineurium. Thus, the operational route must pass between epineurium containing the vessels and the fatty tissue surround-

ing the nerve. Passing through this fatty tissue are the local vessels supplying the nerve as well as the vessels which accompany the nerve. When the nerve is isolated without the epineurium, the blood supply ceases not only of the segmentally approaching vessels, but also of the vessels passing into the epineurium and under it. In such an isolated area, only the intra- /277 trunk network of vessels is retained (B. V. Ognev). Therefore, in isolating the nerve from scars, it is necessary to preserve the layer in which it is to be performed, and if the scars are not thick, they may be intersected and sometimes moved aside with small sharp scissors or tweezers, directing the ends of the latter toward the connective tissue bands.

During neurolysis, particular attention should be given to hemostasis. The hemorrhaging from the small vessels may be stopped by applying gauze soaked in warm physiological solution. The vessels which continue to hemorrhage after this are ligated with thin catgut (N. N. Burdenko). Some authors (B. G. Yegorov) insist on the application of properly performed electrocoagulation as the best method of hemostasis, others abstain from the application of electrocoagulation on the muscles near the nerve trunk and on the nerve itself, since this motivates the swelling reaction which arises at any area where electrocoagulation has been performed. This position, as indicated by B. G. Yegorov, is incorrect if the coagulation is performed properly and is not used as a method of cauterization or burning.

The performance of the neurolysis operation is sharply altered if the neighboring tissues are involved in the scars. It should be taken as a rule that parallel with the nerve it is necessary to isolate involved tendons from the scars, depending on the sphere of the operations. In performing tendolysis, it is necessary to strive toward complete freeing of the tendon from the scars, otherwise it is difficult to

their good mobility in the future. A necessary condition for retaining the mobility of the tendino-muscular apparatus should be the careful treatment of the nerve branches which enter the muscles. Particular attention was given to the scars which simultaneously pressed upon vessels and nerves. These scars were thoroughly removed from the artery, vein and nerve, since they were often the reason for the severe pain symptoms. Cases were often described in which it was considered expedient not only to remove the rough scars from the vessels, but also to excise the sympathetic plexus of the external membrane of the artery above and below the scar. This desympathization operation, which often eased the pain, led to an improvement of the vascularization of the peripheral region of the extremity.

With injury to the vessels and the presence of scars, it was sometimes necessary to excise the cicatrically degenerated portion of the vessel, i.e., to perform arterioectomia. These operations undoubtedly have a great practical significance, since, according to the data for the development of illness histories, combined injuries to the vessels and the nerves were observed with comparative frequency. With combined injuries to the bone and the nerve, neurolysis has its specifics. Most often there was a compression or an inclusion of the radial nerve into the callous formed after firearms fractures of the humerus.

The ulnar nerve, as a result of its close anatomical interrelationships in the area of the elbow joint, was easily compressed and pinched with firearms injuries to this joint.

According to personal observations, a number of other compressions of the major nerve trunks by bone fragments were observed: the brachial plexus -- by fragments of the clavicle, the entire neurovascular fascicle of the brachium -- by the altered humerus.

In these cases to isolate the nerve it was necessary to resort to bone forceps, with the aid of which the bone masses were removed. This should be done very carefully, since it is possible to injure the nerve. The bone should be removed not only above the nerve, but also from the sides, since it /278 is very difficult to extract the nerve from the narrow osteal bed without damaging it.

As a result of various "choking", the nerve lost its structure to such a degree that sometimes it was necessary to resort to its resection. This question was solved after determining the electroexcitability of the nerve during the operation.

Studies on the conductivity of the exposed nerve were performed with faradic current with the aid of a bipolar electrode. It should be stressed that electrical stimulation of the nerve must be performed according to the existing rules of physiological electrodiagnostics. If in doubtful cases upon stimulation of the nerve above the point of its injury the motor effect in the muscles was not evoked or individual small muscles reacted, nerve resection was indicated. If, however, the greater part of the muscle contracted, resection was not indicated and the operation could be limited to neurolysis.

After the performed neurolysis followed the proper formation of the new bed for the nerve. The bed is usually formed of muscle tissue. Here it is very important to prevent the nerve from adjoining the bone tissue, isolating the nerve with a good layer of muscle lining. This was particularly necessary when the bone was afflicted by the inflammatory process and simultaneously with the neurolysis it was necessary to perform sequestrotomy (fig. 122).

Thus, after operations performed on the radial nerve involved in a bone callous, deep parts of the triceps muscles are sutured over the bone, then the nerve is placed, and the more superficial layers of the triceps muscle are sutured over the nerve with individual very sparse sutures.

When there is injury to two nerves, for example the median and the ulnar, in the middle portion of the brachium, after neurolysis it is expedient to place them in the muscle bed separately: the ulnar -- in the opened triceps muscle, and the median -- in the intermuscular fissure between the biceps and the brachial muscles.

After isolation of the ulnar nerve from the osteal scars in the area of the internal condyle, sometimes it is expedient to transfer the nerve to the anterior surface of the elbow bend and to create a muscle bed for it here.

After neurolysis, it is not recommended that the nerve be packed or surrounded by any tissue, fascia, or freely transplanted fat graft, since in the future they will turn into dense connective tissue scars (A. L. Polenov).

With the application of the extraprojectional approaches there is no need to wrap the nerves by additionally introduced tissues, since with this method is it quite possible to cover the nerve with the adjoining undamaged muscle layers.

Neurolysis often represents an independent operation and always precedes nerve suture if the connection between the central and peripheral segment has been disrupted.

Firearms injuries of the peripheral nerves were accompanied by the subsequent development of not only extra-trunkal, but also intra-trunk scars. These changes arose as a consequence

of hemorrhaging in the interfascicular spaces of the nerve. The blood vessels and nerve fibers have a varying degree of resistance to extension. In nerve injuries associated with the extension or overextension of the nerve trunks, the endoneural vessels were the first to suffer (N. N. Burdenko, /279 B. V. Ognev). The disruption of their integrity led to

Fig. 122. Formation of a muscular bed after neurolysis of the radial nerve: the skin and fascia are dissected along the posterior side of the brachium. The radial nerve freed from the scars is retracted, and the thickness of triceps muscle under it is partially sutured.

1 - brachial fascia; 2 - long head of the triceps muscle; 3 - external head of the triceps muscle; 4 - humerus.

hemorrhaging in the area of the intra-trunk spaces of the nerve. The organization of these hemorrhages led to the formation of intra-trunk scars. Interfascicular sclerosis developed, i.e., connective tissue developed which pressed upon the nerve fascicles inside the trunk. The nerve itself was acutely thickened and took on the form of a so-called false neuroma.

Such phenomena were clinically often characterized by sharply expressed pain symptoms, sometimes with retention of the motor function. With severe forms, stable locomotory disruptions were also observed. Pain in this form of disruption often bore the character of causalgia.

To combar scars located inside the trunk (intra-trunk /280
scars), the neurosurgical arsenal includes an operation bearing the name of internal neurolysis. However, very many surgeons and neurosurgeons preferred to perform a resection of the injured area of the nerve with subsequent suture in cases of massive development of connective tissue and acute pain syndrome. This is because endoneurolysis, no matter how thoroughly it is performed, theoretically and practically led to the formation of new endoneural scars.

The technique of the internal neurolysis operation was comprised of the following moments: after isolating the nerve according to the rules presented above, 1% or 2% novocaine solution is introduced under the epineurium. It is introduced vary carefully with a small needle significantly above and below the nerve enlargement and in the area of the enlargement itself. The introduction should be begun at one point above and centrally to the enlargement and move to the periphery. The solution is introduced slowly in order to achieve its gradual movement in the interfascicular spaces of the nerve.

After this the epineurium is opened longitudinally, beginning the incision above the enlargement and, passing through the enlarged portion, ending it below the enlargement. The epineurium is separated somewhat to the sides, freeing the nerve trunk fascicles. A small sharp scalpel is used to very carefully isolate the nerve fascicle above the scar and, grasping it with special blunt forceps, the scar tissue is removed step by step. This is done with all the fascicles which are merged into the scar tissue. The latter is excised from the interfascicular spaces with small scissors. Hemorrhaging is stopped with moist hot tampons with physiological solution. The application of ligatures within the nerve trunk is not recommended, and electrocoagulation should be performed only on the major vessels. Here it is necessary to use very thin optical tweezers, grasping only the end of the isolated artery. After thorough hemostasis and examination of the endoneural space, the integrity of the epineurium is restored with several thin silk sutures.

If internal neurolysis cannot be performed, i.e., if it is impossible to isolate the individual nerve fascicles from the dense scar tissue, it is necessary, as we have indicated above, to perform complete or partial nerve resection with subsequent suturing. Partial resection is performed if less than the entire cross-section of the nerve trunk is taken up by scars. In some cases the operation of internal neurolysis gave satisfactory resulty. More often, however, it led to the repeated development of interfascicular scars, to wasting of the vascular network, and to the return of the pain syndrome.

A cruder and little substantiated intervention on the nerve trunk should be considered the method of splitting, which consists of passing thin threads through the nerve with the aid of a needle. The threads are pulled upward and downward by 2-3 cm from the point of piercing so that they split the nerve into several fascicles. The operation is performed for the purpose of tearing apart the commissures and vessels.

This type of operation was not performed during the Great Patriotic War, and sooner has a historical significance.

A variation of endoneurolysis and unique method of splitting is the operation applied during the war by K. P. Chikovani -- the operation of de-fasicularization.

The de-fascicularization operation according to Chikovani has the same negative qualities as the operation of internal neurolysis, and therefore did not become widespread.

Suture application with injury to the peripheral nerves /281

Suture application with injury to the peripheral nerves is an operative measure which facilitates the normal regeneration of the nerve trunk. It was noted above that based on the results of conservative treatment of peripheral nerve injuries obtained by previous researchers, numerous surgeons and neurosurgeons felt that regeneration of the nerve trunk could occur without suture application. This position, evidently, is true in those cases when the distance between the ends of the intersected nerve is insignificant. Under these conditions there is complete axon growth into the Schwann syncytium of the peripheral segment.

In the presence of large nerve diastases, nerve trunk regeneration was not observed under clinical conditions nor in the experiments of numerous authors. However, the contact of the peripheral and central segment which was achieved with the aid of a suture ensured the possibility of axon growth to the periphery, their subsequent myelinization, and the restoration first of protopathic and then of epicritical sensitivity.

Thus, in those cases of firearms nerve injuries when the series of symptoms developing in the process of wound healing (progressive atrophy of a group of muscles, exclusion of an area of cutaneous innervation from a certain nerve, typical position of the extremity, etc.) indicated complete nerve intersection and the absence of regeneration, the presence of palpated nerves undoubtedly confirmed the diagnosis of severance and was an indication for nerve suture.

In those cases when the nerve retained its anatomical extent, while the electroexcitability determined during the operation indicated complete severance, nerve resection and suture application were also indicated. Partial resection and suture application were also indicated with marginal and central neuromas. Severe causalgia, when the nerve was acutely altered due to the intra-trunk development of connective tissue, was also considered by numerous authors to be indicators for resection of the entire injured segment with subsequent suture application. This intervention facilitated the cessation of pain and created favorable conditions for regeneration. However, there were few followers of this method.

The "primary" and so-called "secondary" nerve sutures are distinguished.

The primary nerve suture is performed no later than 8-12 hours after the injury if the question of partial or complete suture application to the wound is solved in a positive manner. The application of a primary nerve suture under these conditions usually enters into the plan of preliminary wound treatment with its partial or complete closure.

In preliminary wound treatment, it is not recommended that the wound be significantly enlarged, since this increases the space into which infection may be brought. When it is necessary

to broadly excise the edges of crushed tissues with transverse or oblique wounds, it is recommended that small longitudinal incisions be added to the margins of the wound course -- this provides mobility to the wound edges and hidden pockets do not remain in the wound. Turning back the small cutaneous-fascial flaps which are formed, it is easy to find the nerve in its typical place. With this method the wound incision may subsequently be partially sutured, but the muscles and skin above the nerve must necessarily be restored. The nerve edges with firearms injuries are sometimes torn, and most often permeated by hemorrhaging. They are renewed with a sharp knife (a safety /282 razor blade may be used for this purpose, which is held by hemostatic forceps). Thin layers are cut off from the central and peripheral ends of the nerve, while the nerve is being carefully held by special forceps along the injured part of the epineurium. After cutting, a standard epineural suture is applied to the nerve.

The application of a nerve suture -- primary or secondary -- was done by several methods. Usually interrupted sutures are applied to the epineurium at strictly symmetrical points using a thin round ophthalmic needle and very thin silk (fig. 123). The sutures join the epineurium of the peripheral and central nerve segment along the upper and lower edge of the trunk. After the application of two sutures they are usually tied simultaneously. Then, taking the threads into Pean's forceps, the nerve it turned onto itself with its opposite side. This is very easy to perform if the two ends of the tied threads and pulled from the top downward, while the bottom threads are pulled upward, passing them behind the nerve (fig. 136). They it is easy to apply the suture to the posterior surface of the nerve. If the defects are small, the threads should not be pulled too tightly during the nerve trunk suture. Flexing the extremities, it is necessary to give them a position which is most beneficial for contact of the severed nerve endings.

This is usually sufficient to tie the sutures. Some authors (A. L. Polenov, A. G. Molotkov) even recommend that a small space be left between the sutured segments -- this is significant in axon growth.

With a primary large defect in the nerve trunk (in cases where large areas of tissue are torn out), the sutures should be applied "at a distance" with maximal flexion of the extremity. The sutures applied at a distance prevent further divergence of the nerve ends. In suturing the nerve trunk under conditions of preliminary treatment and the possibility of applying a primary suture, the integrity of intersected muscles and tendons must also be restored. Sometimes it is more expedient to first apply sutures to the transversely dissected tendons and muscles, and then to the nerve. Suturing tendons brings the dissected tissues closer together and holds them laterally, which significantly facilitates bringing the nerve edges together. Some surgeons and neurosurgeons used packing with fascia and fat to protect the nerve against scars during the war. However, even before the war, N. N. Burdenko repeatedly warned of the unsuitability of such methodology in papers delivered at congresses and conferences.

After primary suture, the nerve must be surrounded by fresh muscles which are sutured under the nerve as well as over it.

A closed cutaneous suture should not be considered mandatory for all preliminary treated wounds. Sometimes it is necessary to suture a wound partially. In these cases it is preferable to leave sections of the wound unsutured which are located away from the nerve trunk projection. The same is true also of tamponing the wound. The tampon, if it is necessary, should not be introduced over the nerve trunk projection, but only away from it, preferably to the side and away from the muscles sutured under the nerve.

Depending on the location of the wound, in these cases it is sometimes expedient to make a counter-opening, which must be located away from the nerve trunk suture.

With large defects in skin coverings it is more expedient immediately after applying the suture to the nerve to perform plastic closure of these defects with a pedicle · graft or /283 a bridge graft. Such preliminary plasty facilitates the protection of the wound against secondary infection and shortens the wound healing time. If the edges of the wound were badly crushed, plastic closure is postponed for 13-15 days until the wound is cleared and fresh granulations appear. The muscles above the nerve also need to be sutured in these cases. After the suture, the extremity is fixed with a splint in such a position so as to avoid tension on the nerve.

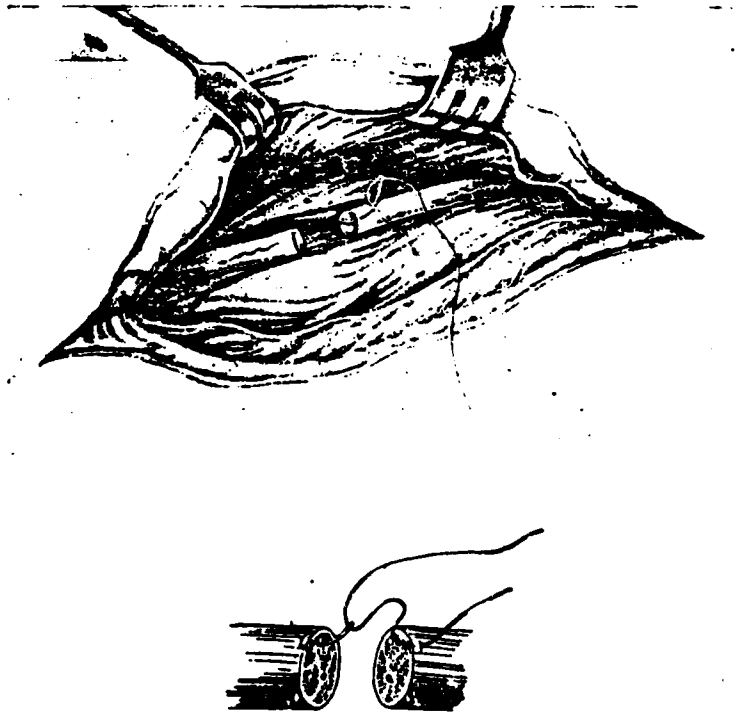


Fig. 123. Nerve trunk suture.

According to the materials for the development of illness histories, primary suture is applied in 0.04% of all the peripheral nerve injuries. According to the reports of A. G. Molotkov, primary sutures on the nerve were sometimes applied during the Leningrad blockage. The wounded were brought in during the first hours after injury, and with surgical wound treatment primary nerve suture application was implemented. After suture application the wounded were not evacuated, leaving them in the Leningrad hospitals.

Later operative interventions on the nerve trunk

The term "secondary nerve suture" should be considered incorrect for most cases. It is better to speak of late suture (I. S. Babchin).

Before the Great Patriotic War, the term "secondary /284 suture" was understood to mean operative intervention on a nerve performed after healing of the wound. This intervention was usually performed no earlier than 4-5 months after the injury was sustained.

During the Great Patriotic War, operations began to be performed on nerve trunks under conditions of a wound which had not yet healed. This operative intervention should also be called "secondary suture". It must retain its descriptive terminology: early operative intervention on the nerve under conditions of an unhealed wound.

A suture applied at this time, in the opinion of the authors performing it, provided early contact of the central and peripheral nerve segment, protected the musculature of the extremity against acute atrophy and sclerosis, facilitated the protection of joints against permanent deformations, the

disappearance of trophic disruptions of the skin, nails, etc. With these tactics, the regeneration of the nerve trunk was accelerated and the function of the extremity was restored sooner.

Among the authors recommending early operative intervention on the damaged nerve under conditions of an unhealed wound, we must mention S. I. Babichev, M. L. Borovskiy, A. G. Neklepayev and others. Two methods were used for approach to the nerve in these cases: either a secondary excision of the unhealed wound according to the type of late treatment and nerve exposure through the formed wound surface was performed, or the principle of extraprojectional approach to the nerve trunk was used. The dissection of the soft tissue and the exposure of the nerve was performed at a distance from the suppurating wound.

In all these interventions, antiseptics in the form of powdered Streptocid and Sulfidine were used, using specially constructed atomizers for this purpose. After application of the antiseptics, the wound was often sutured totally shut.

Subsequent observations, however, showed that Streptocid and Sulfidine as foreign bodies hindered the planned regeneration of the nerve trunk and delayed it. Therefore, numerous surgeons even during the war rejected this methodology.

At the same time, in operating on a nerve in an unhealed or suppurating wound, the surgeon always risks infecting it (N. N. Burdenko). With a flare-up of repeated infection, there is increased danger of the development of extensive muscle sclerosis, formation of gross scars which compress the nerve (B. G. Yegorov).

Most often used under wartime conditions was the late nerve suture, or, as it is called, the "secondary suture".

As we indicated above, the term "secondary suture" should be considered incorrect, since there was no other which preceded it. The term "late suture" should be considered more correct.

A necessary condition for performing a late suture was the complete healing of the wound, which on the average corresponded to the 3-5-th month after injury.

Aside from complete wound healing, as already reported above, various methods of conservative and operative treatment were used. The character of the nerve injury was clarified by chronaximetry, by the perspiration method and by the rhythmic stimulation method according to P. K. Anokhin.

The approach to the nerve was performed by most surgeons along the projection of the location of its trunk onto the skin. Cited above was proof of the greater expediency of extraprojectional incisions with the mandatory excision of the scars. In all these cases the operation began with neurolysis, during /285 which the character of the nerve injury was conclusively clarified.

In most observations it was easy to diagnose complete nerve severance during the operation: the clearly expressed separation of the central end from the peripheral, the presence of a central isolated neuroma left no doubt of this. Sometimes the neuroma was fused with the peripheral segment with a connective tissue band. In this case it was more difficult to pronounce a diagnosis. It was necessary to section the band in order see whether or not it contained nerve elements.

Diagnosis was very difficult in those cases when, according to the clinical picture, there was total severance of conductivity, and complete anatomical severance was found during the operation. Here the pronouncement of a diagnosis was aided by a study of the electroexcitability of the exposed nerve, which made it possible to clarify not only the point of total severance, but also the level at which nerve conductivity was still retained. Operating under local anesthesia, it was possible to be guided by indications of the patient himself regarding the appearance of painful irritations during the study of electroexcitability from one level or another. In operations performed under general anesthesia, however, it was necessary to be guided only by the contractions of the individual muscle groups: with a high current voltage and weak contraction, or rather "twitching", of the individual muscle fibers, inconsequential nerve conductivity must be assumed.

Often simple palpation of the nerve made it possible to find the intra-trunk neuroma, below which there was a scar and complete or partial severance of the nerve fibers.

If a severance of the trunk was found on the operating table, a further operative plan was worked out: could a suture be applied directly or is it necessary to resort to by-stage suturing; will plasty be required, its character, what muscles will be used to form the nerve bed? Immediately before suture application it is necessary to pay particular attention to the treatment of the neuroma. The neuroma and glioma must be completely excised. In order not to remove healthy parts of the nerve capable of regeneration and not to leave scar tissue, a series of sections is taken from the neuroma until a level with a characteristic normal structure of nerve fibers is reached. I. S. Babchin recommends that the boundary between the neuroma and the healthy nerve be determined as follows: the surgeon grasps with forceps the thickest part of the neuroma

with both jaws of the forceps located perpendicular to the length of the nerve trunk. Slightly compressing the neuroma, the forceps are made to slide in the direction toward the healthy part of the nerve. Having reached it, the forceps are retained at the level which seems to be the transitional bourdary between the scar tissue and the more or less healthy section of the nerve. A similar methodology was used by numerous authors, confirming the correctness of this proposal. It is practically very important to cut off the neuroma at once, then the cut obtained is considerably smoother. It is also necessary to renew the peripheral end of the nerve, at once cutting off the glioma with a sharp razor blade (preferably a safety razor).

Macroscopically the ends of the renewed nerve must have a granular surface with well-expressed blood flow. The nerve fibers must not be included in the mass of white shiny connective tissue.

The contours of the "grains" of the peripheral cut are usually more blurred than those of the central, which is explained by degeneration.

In the area where muscles are absent around the wounded /286 nerve, it is expedient to retain the epineurium of the neuroma for transepineural suture (fig. 124).

Among the methods of nerve suture, the epineural suture is generally accepted, in which the threads pass only through the epineurium without touching the nerve fibers (fig. 123). Attention should be directed toward the improper application of a suture, when the threads pass through the substance of the nerve or when the suture constricts the nerve so greatly that

the nerve fiber endings stick out to the sides, emerging from the suture line, or when they are turned into it, not allowing contact. Sutures applied at too great a distance are also viewed as incorrect.

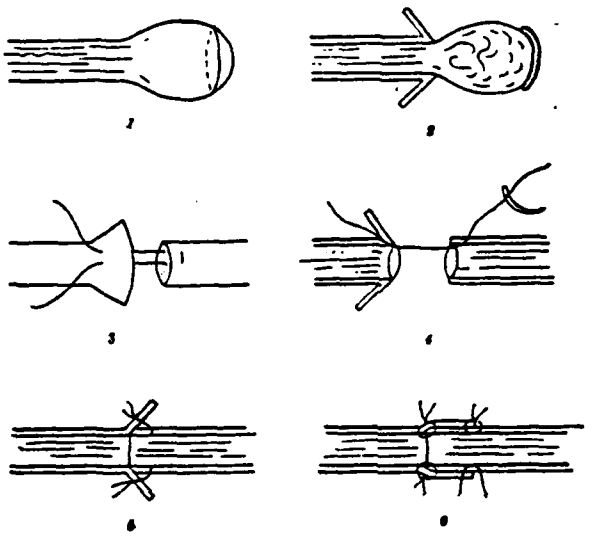


Fig. 124. Application of a transepineural suture.

1 - incision of the epineurium on the peripheral part of the neuroma; 2 - separating the epineurium from the neuroma; 3 and 4 - application of mattress sutures encompassing the epineurium; 5 - appearance of nerve after tying mattress sutures; 6 - application of sutures to the free edge of the central segment epineurium.

With a correct suture, the epineurium should not descend downward with its edges, while the ends of the nerve fibers must be a certain distance from each other. A. G. Molotkov focused much attention on the latter circumstance, maintaining that distance was necessary for the "spread" of the nerve fibers. In any case, it is less dangerous to "under-tighten" than it is to "over-tighten".

The best material for the suture is thin silk or very fine thread (linen). The needles used for nerve suture application are small, circular, and sharply bent. Catgut should not be used for the nerve suture, since it causes a strong inflammatory reaction. In late suture the technique of epineural suture application is the same as with early suture (fig. 123).

The last important moment in the nerve trunk operation is the formation of a muscle bed for the nerve. The nerve may be submerged into a muscle freshly dissected along the /287 length of the fibers after stopping hemorrhaging with a very warm ($40^{\circ}$) tampon or by electrocoagulation (B. G. Yegorov). The sutured nerve is placed in the formed muscle groove, and the muscle is restored above the nerve. It is even better if the nerve can be encased in an intermuscular space. If the nerve is located on a bone, it is necessary to make a muscle lining, separating the nerve from the bone with a muscle layer, as already indicated.

Based on extensive experience in treatment work during the Great Patriotic War, we consider it necessary to once again warn against wrapping the nerve in fascia or a free layer of fat. Numerous authors report on the significant number of patients who underwent repeated operations after "tubage" performed by various surgeons. In all these cases the nerves had been surrounded by a jacket of dense connective tissue which had to be removed.

In the absence of muscle tissue, it was proposed that pedicle muscle grafts be used. However, this is undoubtedly an artificial measure which traumatizes the muscle. And after all, a pedicle graft, due to the change in innervation, nourishment and function, may turn into a connective tissue band and also cause compression of the nerve.

In 1931 G. A. Richter proposed a methodology of transepineural suture which he recommends for use in cases where it is impossible to form a standard muscle bed. This suture protects the nerve fibers against cicatrical compression at the point of their connection (fig. 124).

The substantiation for the application of the indicated suture is the following: with a micro- and macroscopic study of the neuroma it is evident that it consists of two layers: an outside layer, which is an extension of the epineurium, and an inside layer, which consists of a mass of chaotically interwoven fibers compressed by cicatrized connective tissue. The idea of transepineural suture formation consists of utilizing the epineurium of the neuroma. For this purpose, the entire central part of the neuroma is excised, and the excess epineurium is used to cover the suture area. The threads are passed through the fold in the epineurium -- thus the name "transepineural".

The course of the operation is as follows: a circular incision is used to cut the epineurium of the neuroma at a certain distance from its end. The sharp knife is replaced by small bent Cooper's scissors, the short sections of which are used to separate the epineurium from the neuroma and turn it upward in the form of a connection (fig. 124).

After the epineurium is separated from the neuroma, the latter is excised. Also cut off is the glioma from the peripheral nerve segment. Mattress sutures are passed first through the epineurium of the peripheral segment, then under the sectioned neurilemma of the central segment at a certain distance from its edge. Usually it is sufficient to apply two or three such sutures, depending on the thickness of the nerve. In tying the threads, as this is clearly evident from the illustration

presented, the peripheral segment enters the cylinder formed by the epineurium separated from the neuroma. The threads should not be pulled tightly during tying -- the peripheral end will join with the central and proper contact of the nerve fibers will be established (fig. 124).

Then two or three more sutures are applied to the cuff of the epineurium which is bent back, as illustrated in scheme 6 of the same illustration. This suture eliminates the possibility of compressing the axial cylinders with scars and the formation of commissures with the surrounding tissues. Good results were obtained with application of the described suture.

However, the application of this suture is expedient /288 only in those cases when the muscle tissue is absent or scanty, since the enclosure of the operated nerve in the muscle is the basic method of protecting it from subsequent cicatrical compression.

The application of a transepineural suture is a difficult and precise operation which should be used only in necessitated conditions.

Another method which protects the nerve against scars is the application of hemostol plates in those cases where muscle tissue is absent to form the bed. Hemostol or vivocol (particularly processed blood plasma) are stored under sterile conditions in sealed ampules. During the operation the hemostol (or vivocol) is removed from the ampules and squeezed with gauze onto a plate 3 x 3 cm in size, which is used to cover the place of the nerve suture. Such a plate may be prepared from the blood of the operated patient (autohemostol). The Leningrad Institute for Blood Transfusion produced thin fibrin plates which are sterilized in an autoclave. During

the operation they may be used to cut out a cuff of any width and length. This, of course, is much more convenient that other artificial methods of insulating the nerve trunk (A. N. Filatov).

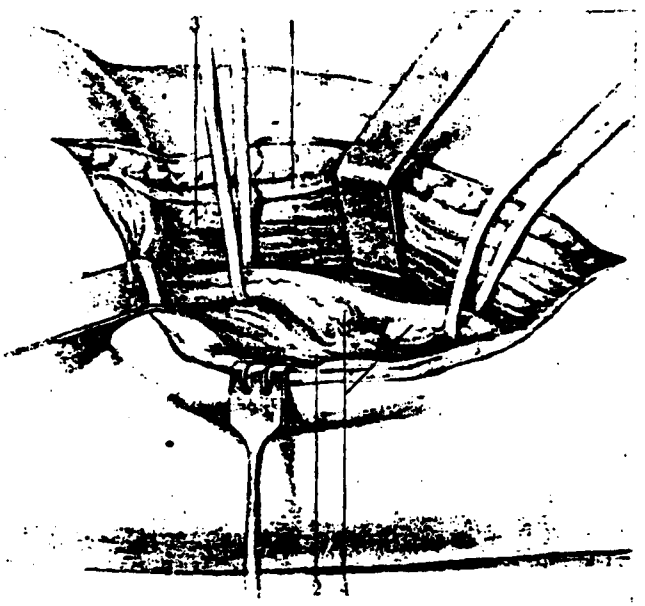


Fig. 125. Nerve trunk suture with partial injury. The sciatic nerve is isolated in the upper third of the thigh.

1 - broad vascia of the thigh; 2 - greater adductor muscle; 3 - biceps muscle of the thigh; 4 - damaged sciatic nerve.

G. Ye. Ostroverkhov proposed and successfully applied the packing of the sutured nerve in amniotic membrane. V. V. Kovanov proposed a catgut tube. Having eliminated by one means or another the possibility of subsequent cicatrical compression of the nerve, the fascia over the muscles or tendons is sutured, and then the skin.

With incomplete severance of the nerve and the presence /289 of a marginal neuroma, it is recommended that the damaged part of the nerve be sectioned away and separated from the healthy part (fig. 125 and 126). The healthy part of the nerve is pushed to the side. In these cases sometimes it is also necessary to use electrodiagnosis in order to establish which parts of the nerve have retained conductivity and which parts have lost it. The second part of the nerve, which ends in a neuroma, is treated the same as the entire injured nerve: the neuroma is cut away until granular surface appears, then the peripheral end is renewed, cutting away the glioma. The renewed ends of the nerve are sutured. According to the materials for the development of illness histories, partial nerve suture was noted in 13.9% of the cases.

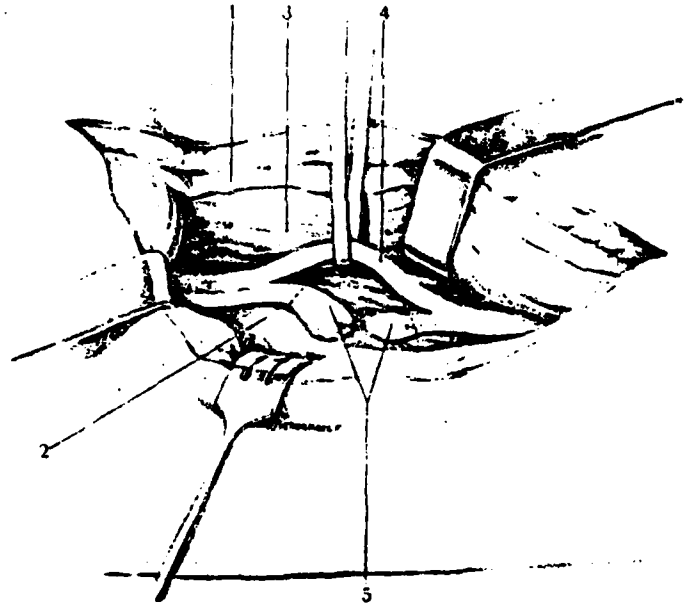



Fig. 126. Nerve trunk suture with partial injury. The healthy part of the nerve is separated from the injured part.

1 - broad fascia of the thigh; 2 - greater adductor muscle; 3 - biceps muscle of the thigh; 4 - retained part of the sciatic nerve; 5 - damaged part of the sciatic nerve.

The healthy part of the nerve takes on the form of a bent loop (fig. 127), but this is not reflected in the conductivity of the nerve trunk.

Triangular excision of a marginal neuroma should be considered a mistake. This method gives poor long-term results (N. B. Chibukmakher).

Some handbooks recommend that in the presence of intra-trunk neuromas, the so-called half-moon excision be performed, which consists of scooping out the intra-trunk neuroma and application of epineural sutures. The described method does not provide contact between the afflicted fibers. As with a marginal neuroma, with the intra-trunk neuroma it is necessary to separate the healthy parts of the nerve from the afflicted parts and to apply a suture only to the afflicted part, /290 pulling aside the parts of the nerve which have retained their conductivity.

However, with such injuries it is important to be very attentive; in part of the cases it may be that complete nerve resection is expedient with subsequent suture application over the entire cross-section of the nerve trunk.

In suturing the soft tissues, it is necessary to retain at all times the position given to the extremity which is most favorable for contact of the fibers of the restored nerve.

After suture application to the skin, the extremity is fixed with a splint or plaster cast, especially if contact of the nerve segments was achieved with some tension. The lower extremity is fixed with a high thick plaster cast (A. N. Yevstropov). In the post-operative period, gradual flexion and extension of the extremity is performed within the limits of several degrees, depending on the pre-given position. The position of the extremity begins to be changed from the 5-6-th day and

usually the norm is reached in 3-4 weeks.

Early movements in the joints of the extremity after nerve suture are very desirable and may be prescribed in the absence of tension on the nerve. Warm baths, light massage, and various types of physiotherapy may also be prescribed early.

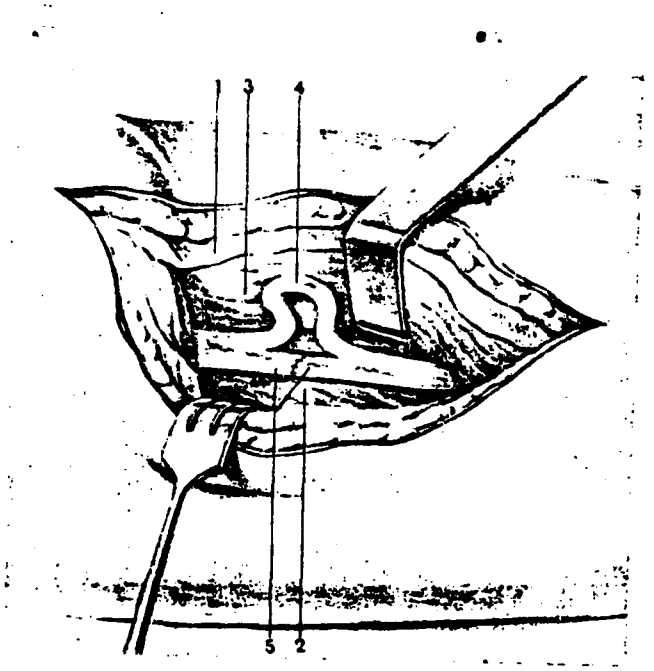



Fig. 127. Nerve trunk suture with partial injury. Sutures are applied to the damaged part of the nerve. The healthy part of the nerve has taken on the form of a bent loop.

1 - broad fascia of the thigh; 2 - greater adductor muscle; 3 - biceps muscle of the thigh;4 - retained part of the sciatic nerve, which has taken on the form of a bent loop; 5 - damaged part of the sciatic nerve which has been restored by sutures.

## The methodology of replacing large defects in nerve trunks /291

Among all the types of interventions on the peripheral nerves, the most difficult is the replacement of large defects in nerve trunks.

Nerve trunk defects arose primarily with fragmentation wounds, accompanied by extensive crushing of the tissues.

Blunt trauma complicated by hemorrhaging in the nerve trunk subsequently often necessitated its removal over a considerable section.

Scar excision with osteomyelitis, joint resections (most often the ulnar) with improper operative technique conditioned the most number of nerve trunk defects.

To solve the problem of surgical treatment of nerve trunk defects, it is first of all important to establish what is understood as the size of the nerve trunk defect and how this defect should be measured.

In isolating the nerve trunk within the limits of healthy tissue and in preparing it at the point of trauma application, the defect is found between the central neuroma and the peripheral glioma. This defect is usually called "primary".

In isolating the nerve trunk from scars until nerve sections appear which are capable of regeneration, the "true" or "final" nerve trunk defect is obtained. P. K. Anokhin defines the concept of "final" defect quite appropriately as consisting of two moments: "... of the primary defect, formed by the traumatizing agent, and of the defect formed after the removal of non-viable parts of the injured nerve".

Cases in which the "final" nerve trunk defects fluctuate from 7 to 12 cm, from 12 to 16 cm, and more rarely from 20 to 25 cm have the greatest practical significance. Once, according to the materials of personal observation, there was occasion to replace a defect in the sciatic nerve measuring 27 cm which occurred as a result of a fragmentary wound to the thigh accompanied by massive damage to the soft tissues of its posterior surface. Usually with defects of less than 6-7 cm it is possible to apply a suture without additional complex measures, using the methods of bringing the nerve segments together.

Small nerve trunk defects may be easily replaced by means of mobilizing the nerve segments. Due to their elasticity, nerve segments diverge at the moment of their complete severance. In the course of several months, which usually pass from the moment the wound is sustained until the operation is performed, scars and commissures are formed which pull the ends of the nerve trunks apart even more and fix them into position.

The central and peripheral nerve segments are isolated gently and carefully without inflicting trauma. Stitching through the neuroma and glioma with thick threads and slightly pulling on these threads, a Kokher probe, anatomical forceps or the aid of a small moist tampon is used to isolate the nerve from its fascial sheath without disrupting the epineurium and the vessels of the nerve. Sometimes in this operation it is necessary to sacrifice one or two small muscle branches. This has no great significance, since several branches go to each muscle. The observed minor hemorrhages caused by the intersection of the nerve vessels are stopped with cotton soaked in warm physiological solution. Recently electrocoagulation has been successfully used in these cases. Very rarely it was necessary to apply thin catgut ligatures, which

should be avoided during nerve operations because excess ligatures facilitate scar formation.

For bringing the nerve ends together, S. F. Deryuzhinskiy /292 proposed changing the position of the extremity. This method is more often called the method of flexing the extremity at the joints. This name is not quite accurate, since for some nerves it is necessary to perform flexion, while for others (ulnar) it is more expedient to perform extension of the extremity. Often both of these forms of correction must be combined in various joints with simultaneous adduction of the extremity. The anatomical works of a number of Soviet authors indicate the values of relative elongation of each nerve with change in the position of the extremity. The knowledge of these exact values computed for each nerve is not so important, since other data also play a role here. It is very important to know what position the segments of the extremity must be placed in during replacement of a defect in one nerve or another. This is indicated in the attached table (M. G. Ignatov).

If the cited measures, whose purpose is to mobilize the nerve achieve an "unloading" position of the extremity, turn out to be insufficient, then to bring the nerve ends together without particular tension it is necessary to apply a suture to the nerve. It is very important during the operation to fix the position given to the extremity.

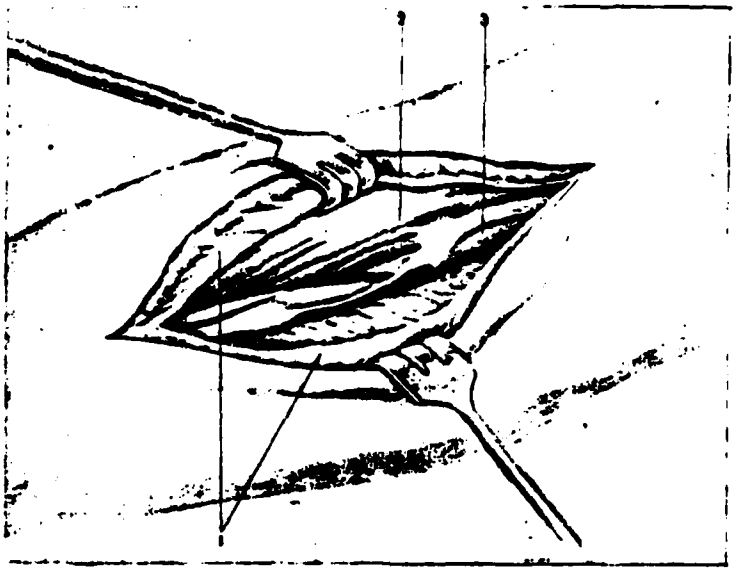
Upon completion of the operation, [this position] is fixed with a plaster or starch bandage or a light splint. Sometimes it is sufficient to fix the extremity with a simple gauze bandage. On the 7-8-th day the splint is removed and the /293 extremity is slightly flexed or extended, depending on the position given to it earlier. Changing the angle of the extremity segments should be done very carefully -- it is better to suggest that the patient himself perform the necessary

movements within limits which do not evoke pain. The new position of the extremity is again fixed.

| Nerve | Level of severance | Position of the extremity facilitating proximity of the nerve ends |
|---|---|---|
| Brachial plexus | Cervical region and subclavian area | Maximal adduction of the brachium to the chest and sharp flexion of the head. |
| | Upper and middle third of the brachium | Maximal adduction of the brachium to the chest and flexion of the arm at the ulnar joint. |
| | Lower third of the brachium, elbow flexion, upper third of the forearm | Maximal flexion of the arm at the elbow joint with supinated forearm. |
| Median nerve | Middle third of the forearm | Maximal flexion of the arm at the elbow with supinated forearm and flexion of the hand in the radiocarpal articulation. |
| | Lower third of the forearm | Maximal flexion of the hand in the radiocarpal articulation. |
| Ulnar nerve | Upper, middle and lower third of the brachium | Maximal adduction of the brachium to the chest and complete extension of the arm at the elbow joint. |
| | The area of the elbow joint and the upper third of the forearm | Total extension in the elbow joint. |
| | Middle and lower third of the forearm | Maximal flexion of the hand with arm extended at the elbow joint. |
| Radial nerve | In the axillary region and in the uppermost part of the brachium | Maximal adduction of the brachium to the chest |
| | In the middle third of the brachium | Change in position of the extremity does not alter the diastase |
| | Lower third of the brachium and the region of the elbow bend | Flexion of the arm at the elbow joint with maximal pronation of the forearm. |

(continued)

| Nerve | Level of severance | Position of the extremity facilitating proximity of the nerve ends |
|---|---|---|
| Sciatic nerve and both its branches | Thigh and the popliteal region | The leg is extended at the hip joint with strong flexion in the knee joint. |



/293

Fig. 128. Defect in the median nerve caused by the application of rapid forced extension of the upper extremity in the elbow joint.

1 - brachial fascia; 2 - biceps muscle of the brachium; 3 - brachial artery.

We know from experiments performed on animals that on the 7-th day after suture application to the nerve it is already impossible to see the threads used to suture the nerve, since they are covered with spreading epineurial tissue. This indicates the sufficiently firm fusion of the nerve segments. Also, during extension the elasticity of the nerve trunk is also used somewhat. On the 14-15-th day after removal of the sutures, the extremity is again given a new position, which is also fixed. By about the 25-30th day it is possible to fully extend the extremity if the angle of flexion (or extension) was not too great. Otherwise, full extension should be done after 1½-2 months. However, even in later periods it is necessary to perform extension very carefully, since the young axons which have grown into the peripheral segment of the nerve have a weak resistance to extension.

> In 1944, patient B. underwent, in his words, suture of the median nerve with application of sharp flexion of the extremity in the elbow joint after the wound had healed along the internal side of the brachium. The stages of subsequent extension were evidently performed too rapidly. Three months after the first operation, the patient exhibited complete severance of the median nerve. During a repeated operation it was found that the nerve was extended at the central and peripheral end in the form of two cones connected by a thin band of epineurium (fig. 128).

The method of extending nerve trunks for the purpose of /294 bringing their ends together has been used for a very long time. It may be applied as a single-moment intervention and as prolonged extension. This method should be resorted to in cases when mobilization of the nerve and flexion of the extremity in the joints do not make it possible to suture the nerve end to end.

P. K. Anokhin showed experimentally that with significant extension, despite the seeming anatomical integrity of the nerve, a large number of deformed and truncated axial cylinders ending

in neuromal receptor formations are formed. Therefore he came to the conclusion that extension of the nerve should be done with great care.

A number of authors have come to the conclusion that there is a certain limit to extension, within the boundaries of which the defect can be liquidated by extension of the ends of the injured nerve. With extension performed with force, there are unavoidable degenerative changes which take place in the central segment. Therefore, it is necessary to stress the fact that extension should be performed very very carefully. Technically this is implemented as follows: after isolating the nerve, the neuroma or glioma is fixed with hemostatic forceps or stitched with a thick thread. After repeated anesthesia (even in operations performed under narcosis), it is necessary to very carefully tug on the threads, at the same time freeing the nerve segments from the fatty tissue and muscle bed. In extending the peripheral segment, the application of great force is allowed, since the danger of severing axial cylinders is excluded here. It is extremely important that the extension be performed parallel to the axis of the nerve without bending it. It is completely inadmissable to "tighten" the nerve, as this is done by certain surgeons and neurosurgeons. We must remember that rough extension of the nerve with retention of its seeming anatomical integrity is what leads to a series of axonal severances at various levels of the nerve trunk. When great force was applied with this method, there were even cases of root severance at the spinal column (Stukkey).

As a result of the specifics of blood supply to the nerve -- the presence of abundant intra-trunk vessels (B. V. Ognev) -- with nerve extension there is intra-trunk hemorrhaging, after whose organization scars are formed within the body of the nerve trunk. Such scars may be the cause of severe causalgia.

Considerable extension of the nerve trunk may also lead to the severance of comparatively large vessels which accompany and feed the nerve trunk (S. I. Yelizarovskiy, B. V. Ognev). Therefore, the rightful desire of the surgeon to apply the nerve suture end to end at the price of any extension should often be counterbalanced by the destruction which occurs as a result of over-extending the nerve.

Close to the described method is the method of prolonged nerve extension. With great defects in the nerve, N. N. Burdenko, isolating the central end of the nerve, sutured around it with skin and performed prolonged extension of this neuro-cutaneous tube until he achieved exposure of the central and peripheral ends of the nerve.

Numerous different experiments were performed for purposes expanding upon the questions of prolonged nerve extension. However, not all of them obtained practical application.

If after using the methods of mobilization, nerve extension, giving an unloaded position to the extremity it is still impossible to apply the nerve suture, then in relation to certain nerve trunks it is possible to resort to the method of their displacement.

Primarily used is the change in the anatomical course of /295 two trunks of the nervous system: the radial and the ulnar. This method creates a new topography for the nerve, which is artificially transferred along the shortest route.

The radial nerve, as we know, passes through a long route, spiralling around the humerus. With large defects in the radial nerve which arise most often on the posterior side of the brachium, transferring the radial nerve to the anterior side of the brachium shortens its route. Such transferrence makes

it possible to additionally utilize the simultaneous flexion of the extremity at the elbow joint in order to bring the nerve ends even closer together for application of the suture (Stukkey).

Judging by the work performed during the war, numerous surgeons successfully used this method. It is difficult to agree with the remarks of certain authors on the inexpediency of this operation, which could lead to injury of the nerve branches (M. G. Ignatov). According to the anatomical studies of M. G. Sirotkina, in approaching the radial nerve from the inside there is a full possibility not only of isolating the nerve, but also of separating the branches diverging to the triceps muscle from the main trunk. Such a separation of the branches and the main trunk is achieved by incising the epineurium and "de-fascicularizing" upward along the trunk of the radial nerve, separating it into its component parts. Therefore by using the described methodology in approaching the central segment of the radial nerve from the inside of the brachium (fig. 96 and 97) there is no danger of injuring the branches which enter the triceps muscle. The deep brachial artery in large nerve trunk defects is usually already involved in the general wound and needs to be isolated, and sometimes even resectioned.

Operative intervention in these cases is performed as follows: the cutaneous incision on the inside of the brachium is begun slightly above the edge of the teres muscle of the back. An oblique incision of 10-11 cm is begun 1.5-2 cm behind the internal sulcus of the brachium (fig. 96, 97). After dissecting the skin and retracting it toward the outside, the aponeurosis of the posterior brachial bed is opened. Bluntly separating the aponeurosis from the muscle, the external (adjoining the bone) edge of the long head of the triceps muscle is exposed. Moving the latter away from the bone, the radial nerve is isolated for the extent of the upper third of the brachium. Usually with extensive nerve injuries on the posterior

side of the brachium this incision is quite sufficient to isolate the entire central segment of the radial nerve together with the neuroma. Sometimes to find the neuroma is it necessary to considerably retract the long head of the triceps muscle from the humerus. With this approach, the branches running to the heads of the triceps muscle are quite visible and easily isolated. In those cases where it was impossible to find the central neuroma from the incision on the internal surface of the brachium, this incision had to be prolonged to the posterior side of the brachium, exposing the long head of the triceps muscle along its entire width. In another inter-muscular fissure -- between the long and external head of the triceps muscle -- the radial nerve was found on the dorsal surface of the humerus. The nerve was thoroughly isolated from the scars, and the neuroma was stitched with thick thread. If during the isolation of the neuroma, difficulties arose in connection with its proximity to the sequestral cavity, with the presence of large venous expansions, then the nerve was cut off from the neuroma, leaving the latter in place (N. B. Chibukmakher). Isolating the central segment of the radial nerve, an intra-muscular canal was formed along the anterior side of the brachium. For this purpose, retracting the skin of the internal incision to the outside, the bed of /298 the digital flexors was opened. This is where the fissure was found between the biceps and the brachial muscle. The fissure was enlarged with dressing forceps and a long gauze tampon was inserted for purposes of hemostasis. The operation was concluded with this first act.

The peripheral end of the radial nerve on the brachium should be opened as described above (fig. 100, 101 and 129), with an incision passed above the median bed of the brachio-radial muscle. The aponeurosis was opened to the inside of the cutaneous incision and the anterior edge of the brachioradial muscle was exposed. Passing the incision to the depth along

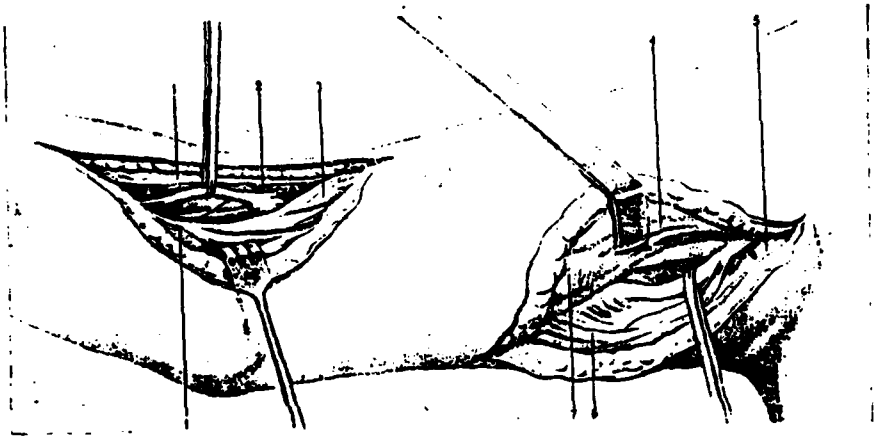


Fig. 129. The methodology of moving the radial nerve in case of its large defects. Isolating the radial nerve by two incisions: the upper -- along the internal edge of the brachium with retraction of the long head of the triceps muscle away from the humerus; the lower segment is isolated along the anterior-internal edge of the brachioradial muscle. /296

1 - forearm fascia; 2 - brachioradial muscle; 3 - brachioradial muscle; 4 - fascia covering the anterior muscles of the brachium; 5 - latissimus dorsi; 6 - long head of the biceps muscle; 7 - internal head of the biceps muscle.

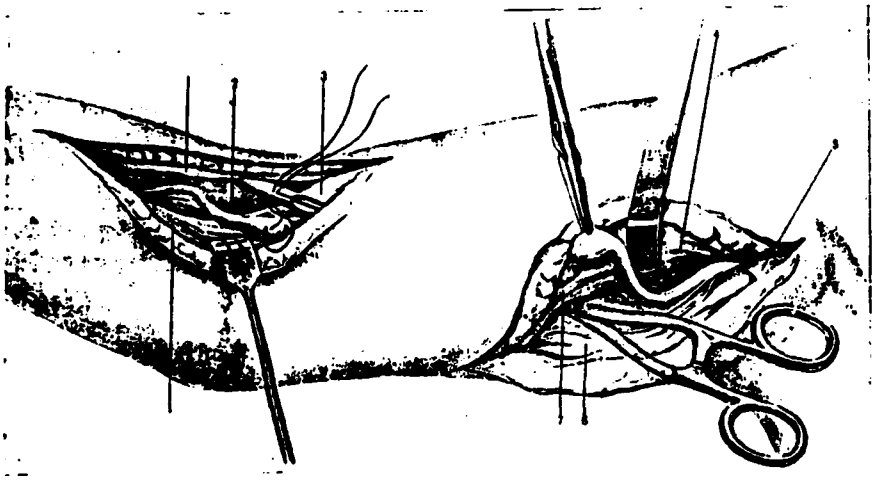


Fig. 130. The methodology of moving the radial nerve with large defects in it. /297

1 - forearm fascia; 2 - brachioradial muscle; 3 - internal brachial muscle; 4 - fascia covering the anterior muscles of the brachium; 5 - latissimus dorsi; 6 - long head of the tricepe muscle; 7 - internal head of the tricepe muscle.

the anterior edge of the brachioradial muscle, the trunk of the /298
radial nerve was located. With large defects in the nerve it was expedient to adhere to this particular muscle edge in approaching the nerve, since the radial nerve is anatomically and physiologically tied specifically with this muscle group after entering the bed of the lateral flexors and to the terminal branchings of its locomotory fibers. No matter what scars pull back the radial nerve, it was organically tied with the muscle group of the lateral extensors, within the limits of which it is easy to find (fig. 101 and 129).

The peripheral end of the radial nerve which was isolated and freed from scars was, like the central segment, stitched with thick thread through the glioma. It is more expedient to cut off the latter after the nerve has been moved to the new muscle bed (fig. 130).

If during the search for the peripheral segment of the radial nerve the anterior fascial bed of the brachium was not damaged within the boundaries of the operative wound, it was immediately opened to the outside of the biceps muscle tendon, and the fissure between the biceps and brachial muscle was exposed (fig. 130).

The fissure was bluntly opened with dressing forceps. The latter were moved into the intermuscular space until they grasped the tampon or until the dressing forceps appeared on the side of the upper incision located along the inside of the brachium. The previously inserted tampon was removed from the intermuscular fissure, the branches of the dressing forceps were opened and grasped the threads with which the upper neuroma had been stitched. Lightly tugging on the thread, the upper nerve segment was passed between the biceps and the brachial

muscles. The extremity was bent at the elbow joint in order to bring the nerve segments to be sutured closer together. To facilitate suturing, the biceps muscle was retracted with a blunt hook toward the inside. After cutting off the neuroma, the nerve was sutured end to end. The peripheral end of the nerve could also be pulled to the central end, as illustrated in fig. 136. This depended completely on the length of the segments and was clarified quite easily during the operative intervention.

The edges of the muscles are brought together above the sutured nerve. This is very easy to do, since the transferred nerve turns out to be almost wholly covered by the biceps muscle, while the point of the suture should best be located in a fresh, untraumatized intermuscular bed, between the biceps and brachial muscles. This method made it possible to bring together defects in the radial nerve up to 10 cm in length. It is true that such large defects could also be covered, using along with the transfer also sufficient mobilization of both segments, slight tugging on the nerve trunk, and as we said before, using considerable flexion of the upper extremity in the elbow joint.

According to the materials published during the Great Patriotic War, positive long-term results were obtained in using this method after firearms wounds.

With large defects, the ulnar nerve may also be sutured end to end after being moved to the anterior surface of the cubital fossa. As we know, the ulnar nerve, going from the /299 brachium to the forearm, sharply deviates to the inside of the midline, lying between the internal condyle of the humerus and the ulnar process of the ulna (fig. 131). When the extremity is bent, the ulnar nerve, fixed in its osteal canal, is tightened

all the more. Consequently, the method of flexion with retention of the anatomical position of the nerve cannot be used with defects of this nerve. Extension facilitates the proximity of the ulnar nerve segments. However, with great defects, extension alone is insufficient for suturing the nerve end to end. However, isolation of both ends of the nerve and their transferrence to the anterior side of the cubital fossa with simultaneous flexion of the elbow joint make it possible to suture the nerve with defects of 10-11 cm. Two methods of transferring the ulnar nerve are described. The first of them should be considered the more anatomically substantiated.

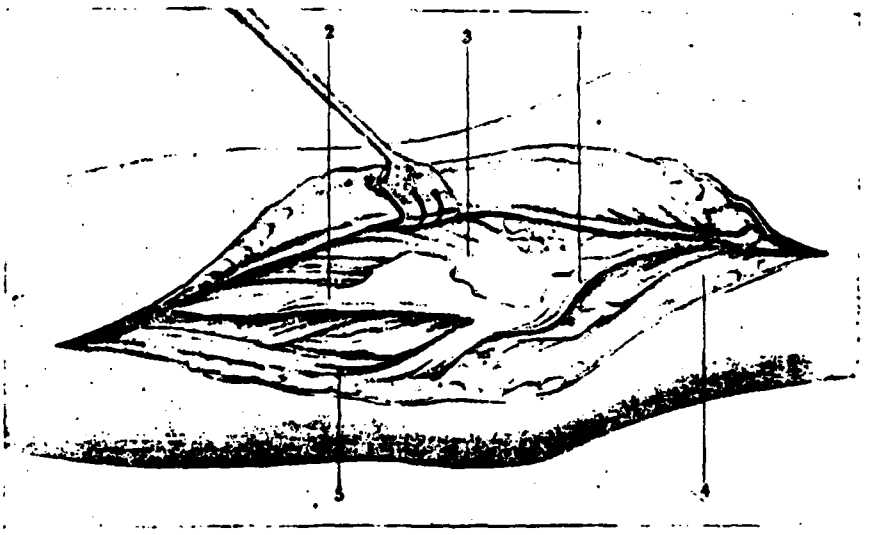



Fig. 131. The methodology of transferring the ulnar nerve with large defects in it.

1 - fascia of the triceps muscle of the brachium; 2 - forearm fascia; 3 - forearm flexors; 4 - internal edge of the triceps muscle; 5 - ulnar flexor of the hand.

The course of the operation with use of the first method is as follows: a large straight cutaneous incision is drawn immediately forward of the internal condyle. The incision is begun 5-6 cm above the cubital fossa. It passes through it and ends on the forearm 6-7 cm below the cubital fossa. Consequently, the incision passes forward of the projection of the ulnar nerve (fig. 105). In transferring the ulnar nerve, the cutaneous incision may also be drawn along the nerve projection, since the nerve will be moved and the suture of the skin and fascia will lie outside the nerve trunk projection.

With the extraprojectional approach, after dissecting the skin and retracting it to the inside, the fascial incision in the lower third of the brachium is made within the limits of the triceps muscle bed. The ulnar nerve is found within the limits of healthy tissue between the triceps muscle and the intermuscular septum. Downward -- in the scars, and sometimes also in the bone fragments (V. D. Chaklin) -- the central neuroma was found (fig. 131). The upper isolated nerve /300 segment, together with the central neuroma, is wrapped in moist gauze moistened in warm physiological solution. In order to move the upper segment of the nerve into the anterior muscle bed it is necessary to slightly incise the internal intermuscular septum (Fig. 132). The isolation of the peripheral segment of the ulnar nerve is performed on the forearm after dissecting the fascia and finding the fissure between the ulnar flexor of the hand and the superficial digital flexor (fig. 132). In the upper third of the forearm it was even necessary to use a knife in order to separate the edges of these muscles (V. F. Zabrodskaya).

For rapid, precise and sure location of the ulnar nerve in the upper third of the forearm, it is always necessary to

adhere to the external edge of the ulnar flexor of the hand during the preparation. Going into the depths along the edge of this muscle, the ulnar nerve should be saught within the boundaries of healthy tissue, and then to isolate it at the point of the nerve trauma.

The ulnar nerve glioma which is isolated at the peripheral end is stitched with thick thread. Tugging on this thread, the peripheral segment of the nerve is gradually isolated from its muscle bed, trying not to cut through the locomotory branches which diverge to the flexor muscles. After this, a considerable amount of novocaine is introduced under the muscle group of forearm flexors. This facilitates the least traumatic separation of the superficial layer of the forearm flexors from the deep layer -- due to the action of creeping infiltrate according to Vishnevskiy. The dressing forceps, passing under the superficial layer of the forearm flexors, form a sort of intermuscular tunnel. In forming the tunnel it is necessary to orient along the anterior surface of the internal brachial muscle, and to bring the dressing forceps out -- in relation to the cubital fossa -- at the external edge of the pronator teres. A gauze tampon is inserted into the formed fissure for purposes of hemostasis.

If the central segment is considerably longer than the peripheral, then it is drawn under the flexors and led out into the fissure between the separated ulnar flexor of the hand and the superficial flexor of the V digit. The solution to the problem of where to draw the nerve segments depends on the level of the injury. Non-transferred segments of the ulnar nerve will be located along the internal brachial muscle (fig. 132). Then the extremity is bent and the possibility of suturing the nerve end to end is determined. With a positive evaluation,

the neuroma and glioma are cut off and the suture applied to the nerve. If it is impossible to apply the nerve suture, the upper and lower segments of the nerve are also isolated and pulled out, after which the ends of the nerve are sutured.

Coverage of the nerve in the upper part of the wound is done by stitching the biceps muscle to the brachial. In the lower part of the wound it is sufficient to place several catgut sutures in order to cover the muscle fissure from which the nerve had been isolated. The place of the suture was usually located under the layer of the forearm flexors in the formed muscle fissure.

The second approach method to the ulnar nerve for purposes of transferring it is anatomically less substantiated. Let us present a description of this method according to M. G. Ignatov. "The cutaneous incision -- as with projectional exposure of the ulnar nerve -- is in the region of the sulcus, behind the internal condyle. The skin and subcutaneous fatty tissue are broadly retracted to both sides. The deep fascia is dissected in an arc form. The ends of this arc-type incision are found: one -- more distally, the other -- more proximally of the internal condyle, i.e., one end is at the lower third of the brachium, and the other is at the upper part of the forearm. Both ends lie on the line of passage of the ulnar nerve. The incision through the deep fascia is drawn from one point to the other in an arc fashion, in such a route so that the apex of this arc passes along the internal edge of the brachial process of the ulna. Now, if we fold back /301 the formed flap of fascia, it is easy to isolate the ulnar nerve under it at the posterior edge of the internal condyle and to transfer it to the anterior side. Securing the nerve in the new position is achieved by tossing the outlined

fascial flap over the nerve and stitching it with several sutures to the underlying tissues in the area of the elbow bend at the radial side of the nerve".

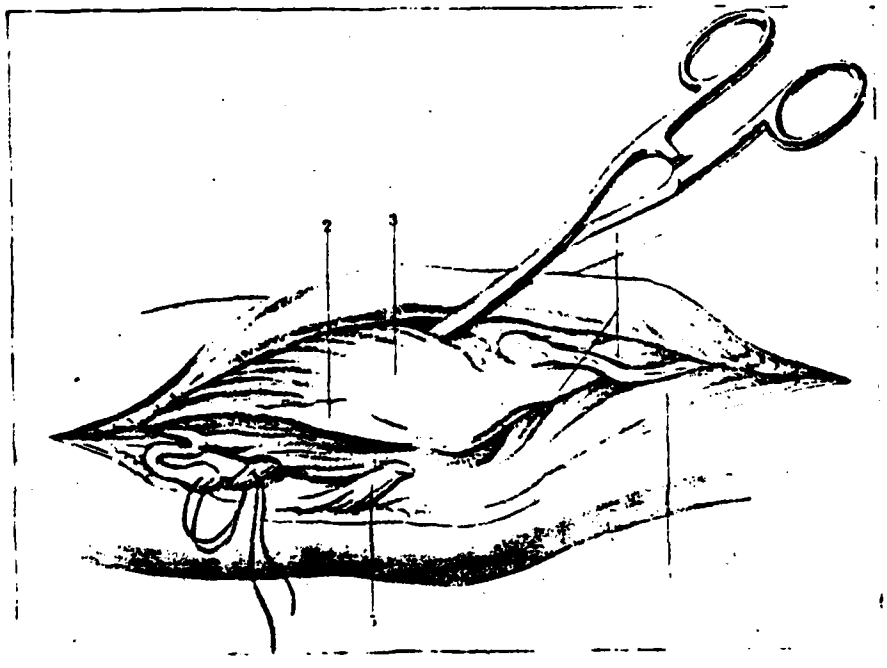



Fig. 132. The methodology of transferring the ulnar nerve with large defects in it.

1 - intermuscular, internal septum of the brachium; 2 - forearm fascia; 3 - forearm flexors; 4 - triceps muscle; 5 - intersected tendon of the ulnar flexor of the hand.

Similar to this method is the approach to the ulnar nerve with chiseled removal of the internal epicondyle of the brachium and folding of the fascial-muscular flap to the outside.

The latter is used to cover the sutured nerve and fix the separated bone.

Favorable results after these operations were observed on the materials obtained during the war. At the present there is already a significant number of positive long-term results after operations of nerve trunk transfers with large nerve defects of firearms origin (B. G. Yegorov, A. S. Lur'ye, N. B. Chibukmakher and others). Suturing the nerve due to shortening the extremity by means of bone resection is related primarily to operations performed on the brachium.

According to the materials of personal observation, this method was used in case of simultaneous injury to the radial nerve and the humerus with formation of pseudarthrosis.

Some authors performed oblique osteotomy in the course /302 of this operation, restoring the length of the extremity with subsequent extension.

The indications for this operation are rather limited, but with simultaneous injury of the bone and the nerve it may enable application of a suture to the nerve, often with the possibility of simultaneous synostosis.

In the case of very large defects when, despite the application of the above-mentioned basic measures, it is impossible to bring the ends of the nerve together, the method of by-stage operations is used.

The method consists of the following: the nerve ends are isolated, mobilized, and extended. The extremity is given the position most favorable for contact of the nerve ends. The neuroma and glioma are stitched with thick silk or a strip of fascia and pulled together as much as possible. Having

sutured the wound, the extremity is firmly fixed in the position of maximal flexion (or extension, depending on the course of the nerve).

In the post-operative period, the position of segments of the extremity is gradually changed, performing extension or flexion. Since the ends of the nerve are fixed, a further gradual extension of both segments of the nerve trunk takes place. The extremity should be straightened very carefully, trying not to inflict pain. Each new given position is again fixed until the extremity is fully extended. A second operation is performed 1-1½ months later: the nerve ends are again exposed, their segments are again mobilized and extended, and the extremity is again given an unloaded position. In a number of cases the diastase between the nerve ends may be eliminated. The neuroma and glioma are cut off and a suture applied end to end.

Performing such an operation in three stages is not recommended, since a very large number of scars and commissures is formed and the regenerative capacity of the nerve drops sharply. A successful case by V. V. Gorinevskaya is described. In the first operation, she brought together the ends of the radial nerve with wire, and in the second operation successfully applied a suture to the nerve, resectioning its pathologically changed ends.

This method, unfortunately, did not find widespread application during the war due to the fear of encountering an even greater number of massive scars in subsequent operations which wound sometimes make isolation and suture of the nerve trunk impossible.

The materials of personal observations show that in late periods of operative intervention this method often gives

satisfactory and even good long-term results. In any case, it should be preferred over all types of plastic methods.

Despite the variety of methods, defects of 12-13 cm or more required the application of plastic methods. These methods were quite widespread in their time, and then were abandoned as unsubstantiated. During the Great Patriotic War they were again used.

Plastic methods of replacing defects in peripheral nerve trunks are implemented by means of using various types of anastomoses and replacement of nerve trunk defects.

One of the earliest surgical interventions on the peripheral nervous system was the method of "nerve graft". It consisted of suturing the ends of the afflicted nerve having the defect into a neighboring healthy nerve after incision of the epineurium of the latter at two points. Using this method, the restoration of nerve functions was anticipated in connection with the erroneous conception of the possibility of axial cylinder growth from the injured nerve to the healthy one /303 and of conducting stimulation through the healthy nerve into the peripheral end of the injured one.

During the Great Patriotic War, N. B. Chibukmakher sutured the ends of an injured nerve to a normal one after incision of the latter and posited that the central, regenerating segment of the afflicted nerve would grow to the sutured paralyzed peripheral segment, thereby restoring conductivity. This method of replacing nerve trunk defects should be rejected, since it has been proven that growth of the nerve in these cases does not occur.

The method of utilizing branches of an injured nerve for covering the defect in the basic trunk was not used for a long time. However, during the Great Patriotic War in the search

for rational methods of replacing nerve trunk defects, a number of authors attempted to use this method (I. A. Gusynin, F. M. Golub). Here, F. M. Golub views the branch used as a splint directing the regeneration of the nerve.

The method consists of taking one or several inconsequential nerve branches diverding above the place of the defect. The branch is mobilized in accordance with the size of the defect, intersected and sutured into the peripheral part of the afflicted nerve. An example may be the utilization of the dorsal cutaneous branch of the ulnar nerve with its significant defect located near the point of divergence of this branch. It is clear that with such a methodology there may be some hope of implementing only partial regeneration of the nerve trunk branches. However, even the latter is quite problematic, since the perception apparata at the periphery of the extremity do not have a representation in the sensory cells of the intervertebral ganglia. The utilization of motor fibers is associated with the loss of work capacity in those muscles from which these branches are taken. Such an operation may be performed only after a strict evaluation of the significance of the individual muscle groups. It is true that the transferred branch which facilitates the partial nerve regeneration may be viewed as a prosthesis (F. M. Golub), parallel to which there will be axon growth from the central segment to the peripheral, particularly at a young age.

Close to the operation of replacing a defect in the main nerve trunk by its branches is the methodology of utilizing locomotory branches of a neighboring healthy herve, whose function must at the same time be weakened. Such an operation may be used also in severe firearms wounds of the fibular nerve and the entirety of the tibial. Therefore, we feel it necessary to cite the operative technique of these interventions.

The operation is begun with a cutaneous incision passing between the projections of the tibial and fibular nerve. The external side of the popliteal fossa is opened up. After mobilization of the edges of skin and opening of the fascia outside the projection of the cutaneous incision, the tibial and fibular nerves are isolated, the heads of the sural muscles are carefully separated along the midline of the crus, and several large muscle branches of the tibial nerve are isolated so as to leave part of the branches for each head and to take branches which are thick enough and most important long enough to be used for plasty. These branches are isolated as far as possible to the periphery and cut off. The common fibular nerve is incised. The peripheral branches are led to the point of the incision and sutured to the exposed surface of the nerve. The epineurium is restored with two or three thin sutures (fig. 133).

After firearms wounds with large defects in the fibular nerve, the renewed peripheral nerve end is led up to the cut muscle branches of the tibial nerve and a suture is applied between them end to end onto the nerves. If it is impossible /304 to cover the point of suture with muscles, it is especially recommended that the suture point be covered with plasty from hemostol or amniotic membrane. Depending on the length of the peripheral segment of the fibular nerve, it is sometimes possible to cover the suture point with the heads of the gastrocnemius muscles. It is necessary to remember the possibility of passing the peripheral segment of the fibular nerve through the external head of the gastrocnemius muscle directly to the branches of the tibial nerve. The non-corresponding incisions in the fascia and the skin protect to a degree the anastomosis from compression by massive scars.

The method of cutting off a part of a healthy nerve and suturing it into the peripheral end of a paralyzed nerve is

in principle similar to the methods presented. This method bears the name of central implantation. This operation should be performed if the function of the nerve from which the section is cut (neurotizor) is less significant than the function of the nerve which must be restored, although even partially. This method may be substantiated also from the standpoint of regenerative processes. At the periphery of the graft taken from the healthy nerve there is excess regeneration (P. K. Anokhin), which facilitates extensive neurotization of the paralyzed peripheral segment.

Peripheral implantation implies the transplant of a peripheral segment of a paralyzed nerve into a neighboring undamaged nerve. The epineurium of the neurotizor is split with a T-shaped incision, and the fascicle intended for innervating the injured nerve is isolated and intersected. The renewed peripheral segment of the paralyzed nerve is brought up to the intersected fascicle and fixed with several sutures. The epineurium above the point of implantation is restored.

The technically negative aspect of these interventions is the insufficient supply of arterial vessels to the nerve grafts isolated with central neurotization, as well as the fact that these grafts remain unprotected due to insufficient epineurium. Moreover, it is difficult to select and isolate fascicles from a nerve taken as the neurotizer. The basis for judging the topography of individual fascicles and branches in the nerve trunk leading to one muscle or another or supplying individual regions with sensory branches, is the data of intratrunk topography according to Shtoffel'. These data have been challenged by numerous authors (D. N. Lubotskiy, A. N. Maksimenkov, A. L. Polenov, A. M. Senyavina, V. N. Shevkunenko,

G. Ya. Epshteyn and others), who presented schemes of the reticular structure of the nerve trunk. However, some clinicians (M. G. Ignatov and others), stimulating nerve trunks in the area of the brachium and the thigh with current during an operation, confirm the possibility of utilizing the data of intra-trunk topography. We must concur with the opinion of M. G. Ignatov on the necessity of utilizing electro-differentiation of fascicles using only a threshold current voltake, since high voltage current invariably stimulates also the nearby nerve fascicles. Technically these operative interventions should be performed precisely, always considering the possibility of injuring neighboring, known healthy fibers leading to muscles which are important in a functional sense.

According to current anatomical data, with implantation of most nerves it is possible to take the central or distal region of the nerve, where it is easier to isolate individual fascicles leading to one muscle or another. Standing out in this respect is the radial nerve, which may be used as the /305 neurotizer specifically in the upper third of the brachium up to the divergence of branches to the triceps muscle. From the studies of M. G. Sirotkina it is evident that the heads of the triceps muscle are dually innervated: by individual fascicles coming from the radial nerve to each head, and by the common sizeable branch which then separates into branches diverging to the individual heads. This common branch, which is still a part of the nerve trunk, may be used as the neurotizer in the upper part of the brachium for the axillary nerve (Stukkey, Shtoffel'). Lower it may be used for the musculocutaneous, ulnar and median nerves. Of the branches of the median nerve, those may be taken for neurotization which innervate the radial flexor of the hand, as well as the branch diverging to the long palmar muscle.

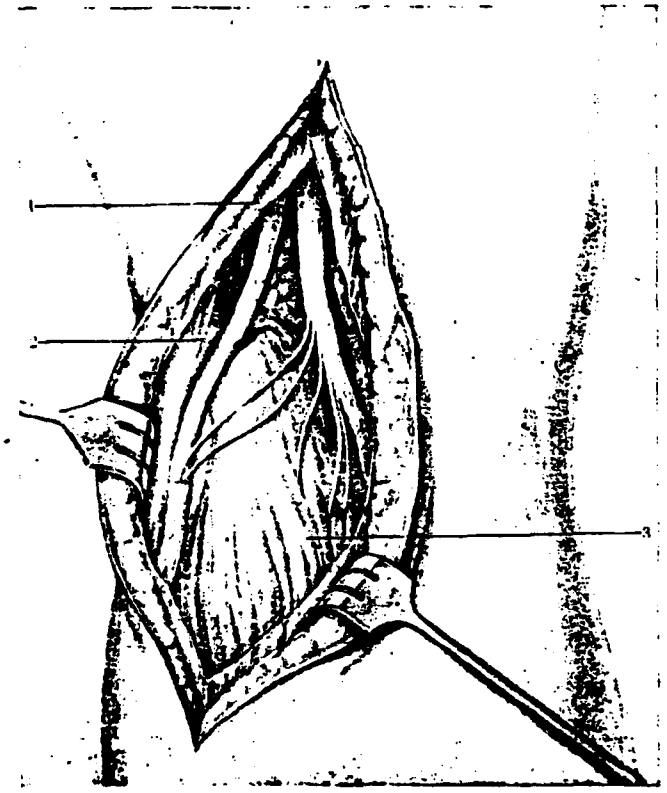


Fig. 133. The method of utilizing the locomotory branches of the tibial nerve with paralysis of the fibular nerve. Incision of the popliteal fossa between the projections of the tibial and fibular nerves. Two muscle branches of the tibial nerve are sutured into the incised part of the fibular nerve.

1 - fascia of the popliteal fossa; 2 - biceps muscle of the thigh; 3 - gastrocnemius muscle.

From the ulnar nerve may be taken a fascicle of fibers /306 leading to the ulnar flexor of the hand.

On the lower extremity it would be expedient to use the fibers of the tibial nerve for restoring the fibular nerve. However, it is better to use the branches of the tibial nerve in the popliteal fossa than to split grafts from the trunk of the tibial nerve (fig. 134).

The use of the fibular nerve to restore the tibial can hardly be considered expedient, since this type of operation may lead to the disruption of the extensor function of the foot and toes.

N. N. Burdenko proposed using the diaphragmal nerve for neurotization. This was implemented by the author himself, as well as by other surgeons in this country who sutured this neurotizer into the peripheral areas of the brachial plexus -- systems of fibers from the median and cutaneous-muscular nerve (F. M. Lampert, V. V. Lebedenko).

L. I. Smirnov and L. P. Lipchina termed "heterotopic neurotization" the growth of central segments of small regenerating nerves into the peripheral segment of a large also injured nerve trunk. By analogy, A. S. Lur'ye called the operation which he proposed for the neurotization of the brachial plexus also "heterotopic neurotization".

With "upper" paralysis of Dyushen-Erb (affliction of $C_5$, $C_6$), when ordinary interventions give no effect due to the large diastase of the roots, it is necessary to neurotize the musculocutaneous, axillary and suprascapular nerves, which in these cases are totally turned off. They may be isolated for neurotization below the clavicle. All the nerves which are taken as

neurotizers are subject during the operation to thorough electrophysiological testing. Both anterior thoracic nerves are isolated and transplanted end to end in the section of intersected cutaneous-muscular nerve (fig. 134).

To avoid tension on the cutaneous-muscular nerve at the sutures with its lower divergence, it must for a certain extent be separated from the external root of the median nerve.

After dissecting the subclavian muscle below the clavicle and separating the musculus pectoralis major from the bone for a certain extent, the suprascapular nerve is found at the very top corner of the wound.

Cutting the fascia of the anterior denticulated muscle under the brachial plexus, it is easy to find the long thoracic nerve which is intersected here. Its central segment is sutured without tension into the peripheral segment of the suprascapular nerve (fig. 134).

The radial nerve is isolated in the very bottom corner of the wound. The dissection of its epineurium facilitates splitting branches off of it to the triceps muscle. After testing with current, two of these branches are intersected at the point of insertion into the muscles. Then the axillary nerve is isolated and intersected at the point of its exit from the posterior trunk of the brachial plexus. The point of section of the axillary nerve is turned downward and sutured with three or four minute sutures to the upward turned branches of the radial nerve (fig. 134).

A. S. Lur'ye cites a case when after severe firearms injury and application of such an operation, flexion was fully restored due to the function of the biceps muscle, while the function of the deltoid muscle was restored halfway. The author

of the operation notes that at the point where elements forming the long thoracic nerve are involved in the pathological process, this nerve may be replaced by the dorsal thoracic nerve, particularly since the exclusion of the latter helps to alleviate the contracture in the brachial joint due to reduction in the pull of the latissimus dorsi muscle.

With the classical form of paralysis of Dezherin-Klyumpke /307 loss of $C_8$ and $D_1$), the two superior anterior thoracic nerves, the lateral and dorsal thoracic nerves, and the suprascapular nerve may be used for neurotization. The suprascapular nerve, in the opinion of A. S. Lur'ye, is a strong neurotizer, but may be used only with complete integrety of the axillary nerve and good function of the deltoid muscle. Technically, the subscapular nerve is isolated in the same way as with the first operation, but intersected at its point of division into peripheral branches. Here the nerve is significantly thicker due to the enlargement of the epineural membrane forming the /308 sheath for the branches diverging to the supraspinal muscle.

Because of its length, the suprascapular nerve may be used only with defects of the lower primary and proximal part of the internal secondary trunk. The suprascapular nerve cannot be pulled to the beginning of the formation of the ulnar and median nerves. The suprascapular nerve is sutured into the medial secondary trunk, as illustrated in fig. 135.

The operation proposed also by A. S. Lur'ye during the Great Patriotic War is also not devoid of theoretical and practical interest. This comprises the use of part of the musculo-cutaneous nerve for neurotization of the peripheral segment of the radial nerve. In this operation, the fibers innervating the coracobrachial muscle and the biceps muscle are retained in the system of the musculo-cutaneous nerve. However, the fibers intended for innervation of the brachial muscle are used to neurotize the radial nerve.

/307

Fig. 134. Neurotization with upper paralysis of Dyushen-Erb. The axillary fossa is opened with intersection of both thoracic muscles and isolation of the neurovascular fascicle. The suprascapular nerve is neurotized by the long thoracic; the axillary nerve is neurotized by the muscle branches of the radial nerve; the musculo-cutaneous nerve is neurotized by the anterior thoracic nerves.

1 - suprascapular nerve; 2 - long thoracic nerve; 3 - brachial plexus; 4 - anterior and thoracic nerves; 5 - musculo-cutaneous nerve; 6 - radial nerve; 7 - muscular branches of the radial nerve; 8 - axillary nerve; 9 - median nerve; 10 - ulnar nerve.

In the course of the operation, the radial nerve is found /308 in the space between the brachioradial and the brachial muscles and isolated upward for the extent of the entire incision.

Opening the space between the brachial and biceps muscle, the musculo-cutaneous nerve is exposed and carefully, without skeletization, it is isolated as high as possible in order to determine the number of locomotory branches which may be used for purposes of neurotizing the radial nerve.

The radial nerve, whose peripheral segment is subject to neurotization, is intersected as high as possible and passed through the fibers of the brachial muscle into the space between the brachial and biceps muscle. The cutaneous-muscular nerve is intersected at such a level that the suture may be placed without tension. If there is an upper branch of the musculo-cutaneous nerve leading to the brachial muscle, it should be intersected and also sutured to the renewed surface of the radial nerve for its more extensive neurotization.

The attempt to find a method of replacing large defects in nerve trunks has led researchers to the idea of using nerves which have been treated in one way or another taken from animals or from man. A transplant which has been fixated by chemical substances is retained for a long time, loses the specific properties of its individual tissue affiliation (V. P. Filatov), and may be prepared ahead of time and used when necessary. Such a transplant may be used to fill a defect of any size.

Nazhott's proposal dates back to 1913 -- to transplant nerves taken from a calf and fixated in alcohol. Nazhott's operation was repeated by numerous authors. The experiments of Gosse and Bertran were published in 1937. These authors

used the spinal cord of a cat fixated in Formalin for their transplants.

In the USSR these experiments were repeated by Ya. I. Begun, Yu. Yu. Dzhanelidze, B. S. Doynikov, N. V. Kovalenko, P. O. Emdin. The results obtained were insufficiently clear, but it was possible to clarify that the surface of the fixated spinal cord direct the regeneration of growing fibrills. By means of thorough morphological testing in laboratories, P. K. Anokhin and B. I. Lavrent'yev were able to establish the fact that nerve fibers of the central segment grow not in the thickness of the spinal cord, but only along the surface. As a result of this, a huge number of juvenile axons is lost in the process of their progression from the central segment to the peripheral, and only singular fibers reach the peripheral end of the transplant. In order to precisely clarify the suitability of one transplant or another, A. P. Anokhina performed a series /309 of experiments with transplant: 1) of a fresh nerve, 2) of a nerve subjected to prior degeneration, 3) of a nerve processed in 20% Formalin, 4) of a fresh spinal cord and 5) of marrow treated with Formalin.

Based on the results of her tests on animals, she came to the following conclusions:

1. Transplantation of a fresh nerve and fresh spinal cord is not effective due to the rapid resorption of the transplant and disorientation of fibers growing from the central segment.

2. The success of transplantation of spinal cord fixated /310 in Formalin according to Gosse and Bertran depends on the positive neurotropic action of the surface of the fixated cord, which represents a convenient route for the oriented growth of the juvenile axons.

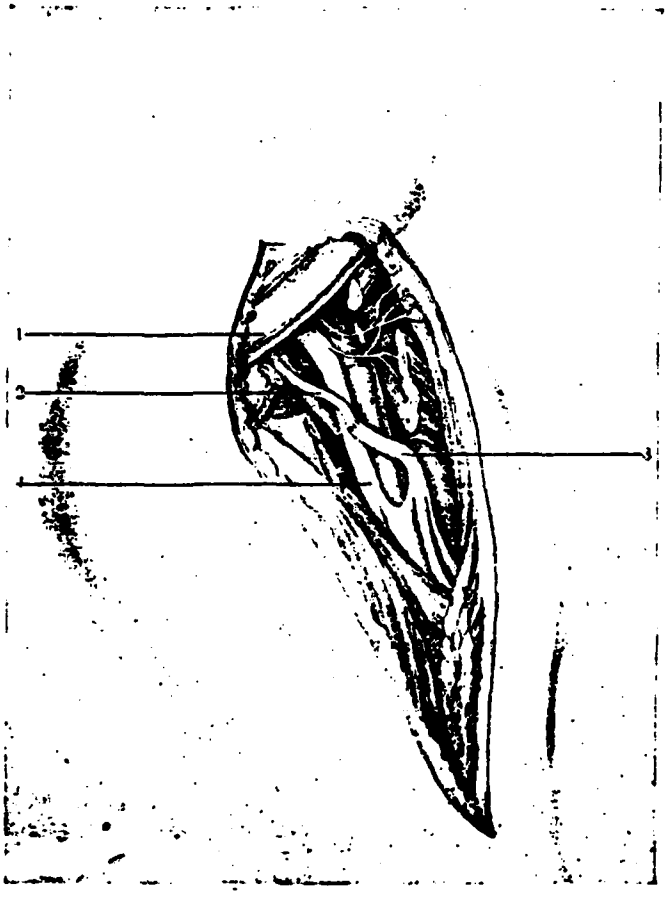



Fig. 135. Neurotization with upper paralyses of Dezherin-Klyumpke. Opening of the axillary fossa was performed by intersecting the musculi pectoralis major and minor, as well as the subclavian muscle. The suprascapular nerve is used as the neurotizer of the medial secondary trunk.

1 - clavicle; 2 - suprascapular nerve; 3 - internal secondary trunk of the brachial plexus and external trunk of the brachial plexus.

3. A nerve fixated in Formalin is the most effective preparation for replacing defects in the traumatized peripheral nerve. And in actuality, under the conditions of experiments performed on animals, the well-expressed oriented growth of axons through the transplant is observed.

Replacement of a defect with a nerve fixated in Formalin or with a similar human nerve taken from a cadaver (M. G. Ignatov) should be used only in those cases when it is impossible to suture the nerve end to end by simpler methods and there are no corresponding conditions for application of the by-stage method.

In transplanting Formalin treated transplants, it is necessary to pay particular attention to the creation of a good muscle bed around the nerve. The laboratory observations of P. K. Anokhin showed that a Formalin treated transplant which is well covered with muscle layers and receives vascularization from the neighboring muscles becomes neurotized quite rapidly.

In transferring a transplant to scar tissue, it very often becomes sequestered and independently isolated or it must be removed in order to close the formed fistula. In 3 cases we observed the sequestration of a Formalin treated transplant under similar conditions. This is also confirmed by the reports of other authors.

The extraprojectional approach to nerve trunks protects the transplant from the formation of scar tissue above it.

The nerve defect determined during the operation is replaced by a Formalin treated transplant of the corresponding size. The Formalin treated nerve should not be cut off with scissors, since this leads to compression and crushing of the

fibers. If the transplant is significantly thinner than the nerve into whose defect it is transplanted, two or three trunks are taken, which are first sutured together and then cut off in accordance with the size of the defect.

The finally prepared transplant is submerged for several more minutes into physiological solution for additional washing of the Formalin at the point of the cut. At this time the surgeon performs complete hemostasis and prepares the muscle bed for the transplant.

The suturing of the nerve and the transplant should always be begun with suturing the epineurium of the transplant. A small sharp needle is inserted into the transplant epineurium, and then the needle passes between the membrane and nerve fibers and its epineurium, exiting at the surface (fig. 123).

The adherance to this rule is quite important for proper fusion of the axons from the central segment to the transplant. With proper suture application, a node is formed above the epineurium, which is not submerged into the suture line.

Certain authors use mattress sutures (A. V. Vishnevskiy), but it is always necessary to start suturing through the membrane of the Formalin treated nerve. In the case of mattress suture application, it is tied over the epineurium of the non-Formalin treated nerve.

P. O. Emdin and others recommend that the epineurium first be sutured at the ends of the transplant and the threads tied, leaving one end of each thread. Then the epineurium is also sutured at the ends of the nerve -- central and peripheral. /311 Bringing the transplant to the ends of the nerve, the corresponding threads are tied in pairs.

The disadvantage of this method would be the very large number of knots, around which stable tissue infiltration may easily occur with resorption vacuoles and subsequent scar development, which of course disrupts the planned regeneration of the nerve elements.

It is very easy to suture the central end of the nerve with the transplant, since the transplant may be slightly lifted during this act of the operation and the sutures may be applied quite easily to the posterior edges.

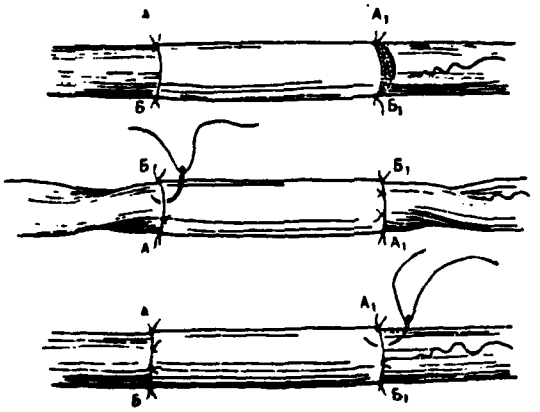


Fig. 136. Replacement of a large defect in the nerve trunk with graft of a Formalin treated transplant.

If the transplant is somewhat wider (which is very preferable), the epineurium of the central nerve segment is incised and then it is quite easy to perform suturing. To increase the cross-section of the nerve, it may be cut diagonally.

After suturing the transplant with the central nerve segment, it is connected with the peripheral segment. There is no need to apply sutures to the posterior surface, as is sometimes recommended with standard end to end nerve suture. The sutures

are applied first to the anterior-lateral edges of the transplant and nerve. With the aid of these threads, the nerve is turned in such a way that the posterior sides of the transplant and the peripheral nerve segment are facing the surgeon, and the suture is applied to them (fig. 136). After performing this part of the operation, reposition of the nerve trunk is performed with the aid of these same threads (P. K. Anokhin).

The points of application of both sutures and the transplant itself must always be covered with a fresh muscle or all the places of suture application enclosed in a fresh intermuscular space or al least covered with a layer of fatty tissue transferred in the form of a wide layer with a sizeable nutrient pedicle. The application of various packings is especially undesirable in these cases, since this hinders vascularization of the graft.

There should not be any sutures above the transplant itself. The muscles which form the bed or the layer of fatty tissue must be sutured to the side away from the transplane. The latter is very important, since it ensures the most rapid fusion of the transplant and protects it against aseptic re- /312
jection.

Sometimes Formalin treated transplants must also be used with partial nerve trunk defects. In these cases, having separated the preserved part from the injured, it is necessary first of all to attempt to suture the partial nerve trunk defect end to end, moving the healthy part of the nerve aside (fig. 125, 126, and 127).

If in adhering to all methods which facilitate contact of the damaged parts of the nerve trunk it is impossible to bring the segments together, grafting of a Formalin treated transplant is indicated. The methodology of suturing in a transplant with partial nerve defect differs little from suturing in a Formalin treated transplant with total defect (fig. 136).

In order to cover the fissure at the point of contact of the transplant with the lateral part of the healthy nerve portion, it is necessary to apply several sutures to the front and back of the transplant epineurium and to the retained part of the nerve.

The results of replacing nerve defects with Formalin treated transplants have turned out to be quite varied for numerous authors. Part of the authors reject the expediency of this method, since, using it during the war, they did not obtain "full or significant restoration of function due to the onset of regeneration" (N. I. Grashchenkov, Z. I. Geymanovich, B. G. Yegorov, M. G. Ignatov, N. I. Makhov, A. L. Polenov, N. B. Chibukmakher and others).

Other authors (P. K. Anokhin, G. A. Rikhter, S. L. Firer, K. N. Shapiro, D. G. Sheffer and others) report that in grafting Formalin treated transplants they observed the restoration of sensitivity as well as movement.

We observed a certain number of cases of Formalin treated nerve transplants with large nerve trunk defects and a large number of grafts of Formalin treated transplants with partial nerve defects, sometimes of insignificant size. In many such cases, which were monitored in detail for a course of a number of years, it was established that there is a certain period of the onset of restoration in movement, sensation, and a number of trophic functions.

However, some authors believe that the improvement in these cases is evidently a result of freeing the nerve from the scar and of insignificant compensation due to surrounding innervation (B. G. Yegorov).

Among personal observations for the period of the Great Patriotic War, there are several cases of the restoration of the brachial plexus, the median and radial nerves with large defects replaced by Formalin treated transplants. A case of restoration of the ulnar nerve with replacement of a defect 17 cm in length was observed.

However, a very large number of negative results cited by various authors (Z. I. Geymanovich, B. G. Yegorov) forces us to re-evaluate this methodology.

Recently (1943) A. L. Shabadash has proposed treating the nerve taken for transplant with alcohol and glucose, also introducing magnesium salts to obtain a porous structure of the transplant. As yet, no clinical results have been obtained after the application of this methodology.

The absence of reliable methods of replacing large nerve trunk defects forces us to present here a description of the various methods which may be used, depending on the circumstances. However, every surgeon must first of all utilize those methods which ensure the possibility of end to end nerve suture. Most comparatively small nerve trunk defects /313 may be replaced by the basic methods: mobilization, flexion of the joints, slight extension, etc.

The methods of transferring nerve trunks which have been worked out in detail and verified present a good means of combatting very large defects in the radial and ulnar nerve.

With simultaneous injury to the bone and nerve, it is necessary to remember the possibility of resection and plasty operations on the bone with end to end suture application to the nerve.

Large nerve trunk defects may be successfully replaced by means of by-stage operations, and in only a small number of cases is it necessary to use plasty methods. Of the latter, evidently, it is not recommended to use suturing of the injured nerve to a neighboring healthy one, using branches diverging above the point of injury for replacing the basic trunk, graft plasty, especially from the central nerve segment, etc.

The methods of neurotization should be clarified and developed. The method of grafting Formalin treated transplants, no matter how it is justified in mass application, must be thoroughly re-worked, since during the Great Patriotic war there were encountered such large defects which could only be replaced by means of transplantation.

## Repeated operative interventions with injuries to the peripheral nerves

Repeated operative interventions after firearms wounds in invalids of the Great Patriotic War had to be performed quite often.

The indications for these operations were varied. Most often the indications for repeated intervention on the nerve trunks were pains and the absence of regeneration.

The absence of the regenerative process in the nerve is a rather complex phenomenon which may be associated with the injury of the nerve trunk, with the disruption of its regenerative capacity due to massive hemorrhaging in the nerve causing the development of connective scar tissue (absence of regeneration or insufficient regeneration). It may also be

associated with insufficient vascularization of the nerve trunk, with the overall acute weakening of the patient's trophicity, with multiple wounds, etc. The absence or insufficient manifestation of the regenerative process should sometimes be associated with those operative errors as a result of which the damaged nerve is not restored to the conditions under which its retained regenerative capacity may be manifested in full measure.

Thus, repeated operative interventions on the nerve trunk are indicated in cases when the new operative intervention can correct an error or imprecision of a previous operation. Of course, at the same time it is necessary to consider whether or not the extremity -- its muscular and articulatory apparatus -- has retained the capacity for restoration. With atrophy of the articulatory bursa of an extremity which is so severely expressed that passive movements in it have become impossible, and with stable contractures repeated operations on the nerve trunk are counterindicated. At the present time we may present and examine some of the errors which have been allowed during interventions on nerve trunks and which have served as the reason for repeated interventions.

One error should be considered the insufficient size /314 of the operative incision. In these cases, most often in the description of the preceding operation, it was recorded: "the nerve was encased in scars; dissection of the commissures was performed". With repeated operative intervention performed within more extensive zones and with a more detailed account of the level of injury, it was possible to find thick scars choking the nerve, and sometimes even the disruption in the integrity of the nerve trunk.

The following case may serve as an example.

Wounded patient B-ov, who sustained a wound on the boundary of the upper and middle third of the brachium, was operated in a specialized neurosurgical institution by an experienced neurosurgeon due to disruption in the conductivity of the radial nerve. In this operation, the radial nerve was exposed by a posterior incision. The nerve was located on the bone in thick scars and commissures. The nerve was separated from the commissures and isolated from the bone by the triceps muscle sutured under the nerve. The muscles above the nerve were also sutured and the wound was closed. Within the course of a year, despite the thorough application of physiotherapy, regeneration did not occur.

The patient was re-admitted after a year. During examination, the absence of conductivity from the right radial nerve was established, the hand and fingers drooped, there was acute atrophy of the muscles in the back of the forearm. Diagnosis: severance of the radial nerve, it was assumed that the injury occurred above the point where the nerve had been examined during the first operative intervention. During the operation, the approach was along the internal surface of the brachium from the axillary fossa to the connection with the incision made by the previous surgeon. When the radial nerve was isolated at the upper third of the shoulder, a large neuroma fused to the bone was found on the end of the central segment. The peripheral segment was also fused to the bone, and upon examination from the back there was the impression of a whole nerve receding into the humerus. The standard manipulations were performed in restoring the integrity of the nerve trunk.

Five years later upon examination, patient B-va exhibited full extension of the hand on the right side. On the radial edge of the back of the hand there was a small zone of hypesthesia.

There are many such examples. Thus, in one case with extensive injury to the brachial plexus the surgeon limited himself only to the examination of the cervical part of the plexus during the first operation, and in a repeated intervention it was discovered that there was damage in the subclavian region. In another case, it was only with repeated intervention on the sciatic nerve after intersection and retraction of the gluteus maximus muscle and the intersection of the piriform muscle that the neuroma was found. The neuroma was

located in the large sciatic opening, stitched with a thick thread, and after this was isolated with great difficulty. In this case, during the first operation in a small incision was used, evidently only the lower edge of the gluteal muscle had been retracted. With this approach it is impossible to find a neuroma which is located higher.

Consequently, the second error which considions the indication for repeated operative interventions was the underestimation of the level of injury.

Repeated interventions were performed in those cases when the operation, although performed in accordance with the level of injury, was nevertheless incomplete. Most often this took place when during the first operation the nerve appeared anatomically whole, which is why only neurolysis with submergence of the nerve into a fresh muscle bed was performed. The expected regeneration which usually sets in faster after neurolysis than after suture application, did not occur. Atrophy of the muscle groups was observed, trophic manifestations increased, and soreness appeared at the point of the injured nerve.

In one such case with repeated examination it turned out that there was a string of small neuromas within the thickness of the nerve. Sometimes in such cases it is found that the body of the nerve is turned into a scar band over a considerable extent. The following case may serve as a demonstration of this.

> The patient, who descended by parachute, hit /315
> the outside surface of the right crus upon landing. There was a large hematoma and pes equino-varus at the place of the contusion. The records of the first operation, performed 3 months after the contusion, note that the nerve was not injured. With repeated intervention taken due to acute, progressive atrophy of the crus muscles, multiple enlargements were found in the thickness of the nerve. Upon examination

of electroexcitability, there were no contractions of any of the crus muscles from the common fibular nerve above the point of the trauma. The nerve was incised, and homogenous scar tissue was found. Nerve resection was performed for the extent of several centimeters to the appearance of a granular surface. A suture was applied to the nerve in the position of acute flexion of the crus, and the extremity was fixed in a cast. Histologically there was scar tissue with individual fibers of regenerating axons. Upon examination 2 years later, wear extension of the sole and the toes was noted, and sensitivity on the dorsal region of the sole had been restored.

N. B. Chibukmakher, who performed a series of repeated operations on the same patients, writes: "With repeated operations in a number of cases it was possible to clarify that the removal of structurally altered parts of the nerve was not done within the limits of healthy sections of the nerve trunk. Such incomplete treatment of the nerve ends and particularly of the central segment cannot lead to elimination of the impairments in the extremity". In these cases the author discovered thickening at the point of the previous suture during the operation, and when the thickening was intersected, a scar was found.

The same author quite accurately noted also another technical error which might condition the absence of regeneration and lead to repeated operative interventions.

In a number of cases it was found that resection of neuromas during the first operation was performed in the place where the most practically important branches diverge from the nerve. For example, the median nerve was resectioned in the cubital fossa in the place where the fascicle of locomotory branches diverges from the nerve to most of the flexors of the hand and digits. In the first operation, these branches were not sutured to the trunk. We may speak of the same types of errors in operations performed in the popliteal fossa on the tibial nerve, in operations on the ulnar nerve, near the

pisiform bone -- the point where the nerve diverges into several branches, etc.

Among the shortcomings and imprecisions of technique which may also necessitate repeated operations we should also mention irrational methods of replacing nerve trunk defects, the use of the dorsal sensory branch of the ulnar nerve (V. A. Gusynin) for replacing a defect in the main trunk, the grafting of a Formalin treated transplant into the scar tissue or into known infected tissue, the replacement of a nerve trunk defect with a muscle according to Moskovich, the formation of grafts from the peripheral and particularly from the central end, the suture of the central segment into the muscle in those cases when it cannot be sutures with the peripheral segment, and the replacement of a nerve defect with Formalin treated spinal cord of an animal.

The following case is of particular interest.

> L. was severely wounded and taken prisoner by the Germans. In connection with the wound, his left lower extremity was amputated in the area of the thigh. On the right upper extremity there was a wound to the median and ulnar nerve with considerable defect. According to the accounts of the patient, a French prisoner surgeon performed a graft of Formalin treated cat spinal cord into the defect in both nerves. The defect in each nerve was then determined to be 8 cm. The surgeon overlooked the possibility of using an excellent nerve autotransplant from the amputated extremity, which could also have been fixated in Formalin.
>
> When L. was returned from captivity 3 years later, total severance of the median and ulnar nerve was established. Although the operation had been performed 3 years ago, the decision was made to subject the patient to repeated operative intervention. During the operation the ends of both nerves were found, and between them the intact transplanted spinal cord, which in placed had been bulbously bloated. Both nerves were freed from /316 the scars, particularly in the area of the peripheral segments. The ulnar nerve was transferred to the

anterior surface of the cubital fossa and acute flexion was performed in the elbow joint. The renewed nerves could be sutured end to end without particular tension.

Thus, in the case presented, the foreign surgeon made a mistake: a method which was physiologically unsubstantiated was used to replace the defect in both nerves.

In a histological examination of the removed cat spinal cord, it was found that its structure had been retained. Axon growth from the central end of the intersected nerve was observed only around the periphery of the spinal cord and then on very limited areas of its surface.

As we see from the case presented, by means of thorughly performed mobilization, transfer of the ulnar nerve and flexion it was possible with repeated intervention to use the method which best ensured the manifestation of the nerve's regenerative capacity, i.e., direct end to end nerve suture.

The next reason for repeated interventions on the nerve are pains. The reasons for these pains are quite varied. In part of the cases the pains arise as a result of the divergence of the nerve ends after suture and, evidently, the repeated formation of painful neuromas.

A. N. Yevstropov in his work gives particular attention to this question. He feels that with a significant defect, the insufficient fixation of a bent and adducted extremity after suture application often leads to the divergence of the nerve suture and to the formation of a new center of irritation in the form of a neuroma.

The renewal of pains after operative intervention may undoubtedly be associated with the development of connective scar tissue around the nerve suture, into which the regenerating nerve fibers grow according to the type of heterotropic innervation.

Earlier it was believed that connective tissue grows into the area of the nerve suture. However, based on modern histological studies we must assume that the nerve grows into the surrounding connective tissue, where the regenerating nerve fibers are pinched. This causes acute soreness of the scar due to its pathological neurotization.

Sometimes the connective tissue grows so extensively over the area of the applied suture and along the entire extent of the operative scar that it becomes necessary to perform a repeated intervention due to the sharp pains. An example of this may be the following case.

> Patient M. was suffering from an injury to the median nerve of the right upper extremity in the central third of the brachium. He arrived at the evacuation hospital with a healed wound and acute soreness in the region of a well-formed transverse scar which intersected the internal sulcus of the brachium. A painful neuroma of the median nerve could be palpated; the pains radiated into the scar. Clinically, there is acute atrophy of the forearm muscles innervated by the median nerve. The region of anesthesia on the hand is typical for the median nerve. The operation was performed under local anesthetic with excision of the scar by oval incision. Two incisions were added to the central and peripheral end of the formed wound, passing outside the nerve projection. The nerve was isolated, and the peripheral and central ends were located. The neuroma was excised and the nerve sutured end to end. The nerve was moved to a fresh bed between the biceps and brachial muscles.
>
> One and a half months after the operation, the pains returned, the patient could not sleep at night and suffered acute weight loss. All types of treatment were tried -- vaccine therapy, UHF therapy, ultraviolet radiation and heat, careful faradization, paraffin therapy, but all were without results. Four months later, due to the severe causalgic type pains, a second operation was performed. The nerve was isolated with difficulty from the layers of thick scar tissue. It had been well restored, but at the point of contact of the nerve segments there was a protrusion which could be palpated without any thickening. At the point of the previous suture a small thin needle was used to introduce 2% novocaine solution.

The scar tissue surrounding the nerve was thoroughly excised. The nerve was again enclosed in the muscle bed. After the operations the pains subsided considerably, but still persisted for 2 more months, in the course of which a large amount of 0.25% novocaine solution was introduced three times into the space around the nerve. /317

After a year and a half there was good regeneration of the median nerve. The patient served as a demonstration at a conference.

Pains occurred in those cases when the surgeon, operating in the area where muscles were absent, wrapped the nerve after suture or neurolysis with a sheet of freely taken fascia or fat. Although even begore the war the inexpedience of this measure was repeatedly stressed (N. N. Burdenko), numerous surgeons in repeated operative interventions due to renewed pain found and removed cicatrically degenerated layers which arose from transplanted fascia and free pieces of skin which compressed the nerve in a thick sleeve.

As already indicated above, extraprojectional incisions, particularly in places where the nerves lie immediately under the skin and the fascia (the inside of the brachium, the anterior surface of the forearm in the lower third), undoubtedly protect the nerves against cicatrical compression (fig. 98). With extraprojectional incisions, the scars are formed outside the nerve trunk projection and at different levels. Consequently, massive scars may rarely be formed above the nerve in such cases. Therefore it was quite often necessary to perform repeated operations on patients due to the pains which occurred as a result of the fact that in the first operation the incision was performed along the nerve projection, often even without excision of the scar. In these cases the longitudinal operative incision was performed along the nerve projection through the existing oblique or transverse

scar. As a result, after the operation there was a complex webbing of acutely painful scars.

In repeated operations, the most difficult was the excision of all the existing scars without making new incisions so that more cicatrical obstructions would not be formed over the nerve. Freeing the nerve from the scars, it was necessary to seek various, often complex methods of covering it.

> As a result of injury to the ulnar and median nerves, patient N. underwent an operation from an incision which ran exactly along the internal sulcus of the brachium. After the operation there was slight suppuration. Upon examination there was a massive scar, which was acutely painful. There was absence of movement in the muscles innervated by the ulnar and median nerve. In the region of distribution of the cutaneous nerves of both nerves there was anesthesia.
>
> The nerve was freed with great difficulty from the dense scar tissue. The central ends of the nerves were clavately enlarged.There were bands diverging from them to the peripheral segments. Excision of the scar tissue to the appearance of granular surface of the cuts was performed. Separate beds were formed for the sutured nerves: the median nerve was placed between the biceps and brachial muscle, the ulnar -- in the fissure of the triceps muscle. The aponeurosis was restored over both muscles. Thus it was possible to protect the sutured nerves against the possibility of new scar tissue growth. The soreness in the area of the scar disappeared. After a year and a half, movement was restored to the muscle group innervated by the median nerve. The lost function of the ulnar nerve was insignificantly improved.

The necessity for repeated interventions due to pain may also be associated with the inadequate treatment of the blood vessels often included in the general conglomerate of scars. In a number of cases the nerves are pulled to the vessels with dense scars running in the form of loops, often the brachial plexus is pulled by thick scars to the subclavian vessels and to the clavicle.

Tied with numerous ligatures (ligature conglomerate), the ends of the intersected and thrombosed vessels may cause pain due to the fact that repeated operative interventions /318 are necessary at the place of trauma, and sometimes away from it.

It was necessary to perform repeated operations on the nerve also in those cases when it was impossible to perform the restorative operation during the initial operative intervention: the presence of severe purulent process, more often osteomyelitis, the impossibility of finding the ends of the damaged nerve in the dense scars; large defects in the nerve trunk when in the first operation after the appropriate mobilization and flexion of the extremity suturing was performed through the neuromas with the calculation that in the second operation the surgeon will be able to suture the nerve end to end. We may remind the reader also of the cases of application of improper technique of triangular excision of marginal neuromas with subsequent suture on only one nerve, while several nerves had been damaged in the injury.

As a rare case we should note the cross-suturing of the median and ulnar nerve in the upper third of the brachium which is found during repeated operation.

In a word, indications for repeated operations on the extremities whose nerves had been damaged are numerous. Often they are indicated not only with nerve injuries, but also with combined injury to muscles, tendons, vessels, bones and joints. This is explained by the fact that with severe firearms wounds the entire complex sheath of the extremity is damaged, for whose restoration it is necessary to have exhaustive precise diagnosis and the participation of an experienced surgeon of versatile education who has a good command of the plasty of various tissues of the extremity.

Thus, the technique and methodology of operations performed on nerves during the time of the Great Patriotic War was not only re-evaluated, but also considerably improved. According to the conditions of combat operations, primary nerve suture was applied very rarely. Suture application to a nerve in an unhealed wound under the cover of antiseptics was tested. The future evidently belongs to the early nerve suture under conditions of widespread usage of antibiotics.

Neurolysis has come to be viewed not as a simple operation of isolating the nerve, but as a complex operative intervention which is the starting point for most operations on the peripheral nerves and during which the final diagnosis is clarified. It has become evident that the statistical comparison of the results of neurolysis and suture is incorrect, since each of these operations has its own strict, fully determined indications.

Aside from the standard projectional methods of approach to the nerve trunks, numerous surgeons in this country have also used extraprojectional methods. These methods were proposed in the USSR as early as 1937.

Again the difficult questions of replacing large nerve trunk defects were reviewed and a number of basic methods were determined which provide the possibility, especially for individual nerve trunks, of end to end suturing.

The methods of replacing very large defects require subsequent work in the direction of accelerating regeneration and developing a method of preparing more complete transplants.

The deeply thought through by-stage treatment of a patient ensured in the overwhelming majority of cases the treatment of the entire extremity as a whole. Physiotherapy and exercise

therapy which had been performed on a mass scale in the pre-operative period made it possible to implement the operative interventions on the nerves.

The implementation of the same measures in the post- /319
operative period facilitated the acceleration of nerve trunk regeneration and the restoration of work and combat capability of the heroic warriors of the Soviet Army.

Basic methods of conducting the post-operative period

Two principles were placed at the basis for conducting the post-operative period in operations on the peripheral nervous system: 1) thorough fixation of that section of the extremity where the operation was performed, 2) planned implementation of early overall exercise therapy and early movements in those sections of the extremity which did not require rest. For this purpose, in the post-operative period with operations on the upper extremities, early ambulation was recommended and implemented. After an operation performed on the peripheral regions of the upper extremity, the patient was already allowed to walk around the ward on the next day. After operations on the brachial plexus, depending on how the patient responded to the intervention and whether a simultaneous operation was performed on the vessels, the period of bed confinement was somewhat lengthened. However, already in bed the patient began performing a series of physical exercises which, aside from the lower extremities and torso, included also the healthy upper extremity.

In operations on the lower extremities, especially if acute flexion in the joints and extension of the nerve trunks was used, the patients remained in bed for a period of 20-30 days.

The same principles of early physical exercise were also applied to the upper half of the torso. The bandage applied during the operation which fixed the position of the extremity was examined in detail. If necessary, additional fixation was performed, plaster cast application, etc. If cyanosis or pressure from the bandage were present, cuts were made or windows cut out in the bandage, etc. In such cases these measures were necessary, since with nerve injury the sensitivity was often either totally lost or weakened, as a result of which bedsores were easily formed. If it was necessary to use a bandage, the given position of the extremity was strictly fixed so as not to disrupt the integrity of the applied suture.

The introduction of the standard plaster wire splint during the war should be considered very convenient. The details [of these splints] were thoroughly worked out as applicable to the injuries of various nerve trunks (M. G. Taborisskiy, S. L. Firer and others).

The first wound revision was conducted no less than on the 5-6-th day, if there was no elevation in temperature, complaints of sharp pains in the operated extremity or of the emergence of peripheral disorders, etc.

Obviously, if the operation ended in the introduction of a tampon, the bandages should be changed earlier in order to remove the tampon.

During re-bandaging and wound revision, the extremity should be strictly held in the position it was given during the operation.

During bandage changes, particular attention was given to hematomas and stretching of the skin: hematomas were immediately empties, since they cause severe complications,

the emergence of new scars and commissures around the operated nerve. The sutures had to be removed from the skin in places where stretching was found. The personal experience of numerous surgeons and neurosurgeons shows that healing of part of the wound with partial stretching did not reflect upon the restoration of the nerve trunk. However, the penetration of infection into the depth of the wound led to severe complications, /320 particularly to ascending infectious neuritis, to the development of intermuscular scars. During the first wound revision and partial removal of the cutaneous sutures, usually the angle at which the extremity was flexed or extended was changed somewhat. This first change in position should be done very carefully, without applying any force, particularly in nerve sutures under great tension.

From the materials of personal observations it follows that it is better to have the patient himself extend or flex the extremity: the patient spares his extremity and the sensation of even insignificant pain will force him to refrain from further forced change in position.

The new position given to the extremity is again thoroughly fixed with a plaster bandage or splint. Bandages of the by-stage plaster type are very convenient for these purposes, in which two parts of the bandage are located outside the wound, and only the middle part of the bandage is removable which is located over the operative wound.

Skin irritation or redness around the wound was eliminated by moist alcohol bandages.

If severe infection developed in the wound, not only were the cutaneous and muscular sutures removed, but contrapertures were also carefully applied outside the nerve trunk projection. The introduction of penicillin into practice sharply reduced

the percentage of suppuration, bringing to a minimum the necessity of applying contra-apertures. With the use of antibiotics, the post-operative period began to proceed much more easily. The rapid liquidation of infection made it possible to apply secondary sutures, which protected the extremity against the formation of rough scars, especially with the use of incisions running along the nerve trunk projection.

Pain after operations on nerve trunks was a frequent complication and also a source of extreme suffering for the patients. The fight against this pain must be begun from the very first day of the post-operative period. Most often it was associated with irritation of the nerve and vascular trunks, which were subject to surgical action. The character and intensity of the pains were evidently associated with the structure of the nerves on which the operative intervention had been performed. Thus, the presence of a large number of sensory and vegetative conductors in the nerve usually caused a more acute irritation. Operations on the median and ulnar nerves were accompanied in the post-operative period by a more acute and prolonged soreness than an operation on the radial nerve. Combined operative interventions on the nerves and vessels, on the nerves and bones were also distinguished by a greater painfulness in the post-operative period. The condition of irritation of the nerve trunk conditioned by the course of the wound process before the operation was significant. In the presence of severe pain stimuli (causalgia), pains in the post-operative period sometimes passed quickly, and sometimes became acutely exacerbated. The patients endured the pain in the post-operative period quite individually.

After the operations performed on nerves, the patients were primarily given antipyretics of the type pyramidon, aspirin, antipirin, phenacetin and others in combination with caffeine.

It should be noted that morphine had a bad effect on these pains. It should be prescribed only in those cases when the patient cannot fall asleep after taking soporifics -- veronal, luminal, sodium amital. Usually, however, the combination of antipyretics and soporifics (especially sodium amital) ensures good sleep.

In 3-4 days, if infection has not developed in the /321 wound and the pains have subsided, medicinal treatment may be discontinued if there are no special indications for it.

Sometimes the pains persisted, and upon examination of the wound neither infection nor pressure by the bandage could be found. In these cases, urotropine is prescribed prophylactically, or in the case of localized pain in the joints -- cinchophen. An excellent substance eliminating pain is vitamin $B_1$. Recently, penicillin has been prophylactically prescribed.

The success of sleep therapy in cases of acute pains in the post-operative period forces us to conclude that after all operations associated with massive irritation of the peripheral nervous system, it should be used prophylactically.

In operative interventions related to acute pains of the causalgic type, particularly if thalamic syndromes have already been noted, sleep therapy should be used in the post-operative period (V. V. Zikeyev).

The appearance of sharp pains on the 4-th and 5-th day, and sometimes the exacerbation of pains by this period forced the physician to assume not only the presence of infection in the wound, but also infection spreading along the nerve trunk with an accompanying picture of infectious neuritis and plexitis. In such cases, aside from antipyretics and iodine preparations, polyvalent staphylococcus and streptococcus vaccines taken in even doses have been effective (M. S. Margulis). At the

first sign of infection, 0.3-0.4 g of each vaccine was taken, with a total, consequently, of 0.5-0.8 g. With secondary infection, which appeared in 3-4 days, a total of from 1.2 to 1.5 g was introduced, with the third -- around 2 g. At the present time, due to the use of antibiotics -- penicillin and streptomycin, as well as vitamin $B_1$, the use of vaccines has been reduced.

In a number of cases with unceasing pains, in the absence of suppuration, and when medicinal therapy did not give positive results, particularly in the later period, many neurosurgeons performed repeated operations, but these already on the vegetative conductors. The basis for these operative interventions, which were often successful, was the theory of stimulating the vegetative path (A. M. Grinshteyn). The substantiations, indications and technique of these operative interventions are presented in detail in the corresponding chapters.

The concept of conservative therapy in the post-operative period includes physio- and mechanotherapy. However, it is more correct to examine these measures as a continuation of the treatment started before the operation. The character of this treatment must be strictly tied with the character of the injury and with the subsequent operative interventions. According to the materials of personal observations, individual cases were isolated when, in the absence of an exact diagnosis and in the presence of cutaneous anesthesia on the extremities, radiation therapy was used which caused the formation of ulcerations which did not heal for long periods.

In the overwhelming majority of cases, physical methods of treatment facilitated the dissolution of infiltrates in the scars during the pre-operative period, protected the muscles

against atrophy, the joints against rigidity, etc.

In the post-operative period, the complex of physiotherapeutic measures was continued, and the earlier it was begun, the better the reduced function of the extremity was restored. After neurolysis it was possible to prescribe baths, electrization, massage, passive and then active exercise, and work therapy quite early. The introduction of the latter into the evacuation hospitals played a large role in the restoration of combat fitness of soldiers in the Soviet Army. After the neurolysis operation, therapeutic exercise must be started from the 5-6-th day (I. Yu. Tarasevich). Of course, in prescribing all these measures it is necessary to consider cases of neurolyses accompanied at the same time by osteomyelitis, operations on the vessels, the presence of anaerobic infection in the case history, etc. In these cases, physiotherapy was started somewhat later, the physiotherapy was combined with antiseptics, antibiotics, etc. In the presence of a wound, ultraviolet irradiation of the open wound surface and the entire extremity was used. Of course, all these measures were conducted with the condition of consultation between the operating surgeon and the treating physiotherapist. The lack of communication which sometimes occurred between specialists had a negative effect on the effectiveness of the treatment. /322

In cases of suture application to the nerve without tension, all the measures facilitating the acceleration of regeneration were also begun early. However, the time at which they were prescribed and their character changed somewhat depending on a number of complicating moments: flare-ups of infection, the emergence and exacerbation of the pain syndrome, etc. In these cases, UHF therapy, mud applications, paraffin, ozocerite, etc. were used.

Comparatively soon after suture application, head procedures and particularly baths, light massage and very careful exercise were prescribed. Electrization in early periods after suture application was considered to be counterindicated by a number of authors. V. K. Khoroshko had a somewhat different opinion, considering the very early physiotherapy, and particularly electrization, after nerve suture application to be indicated.

Galvanic current was used to intensify the regeneration of the nerve trunk in the post-operative period. Faradization was used less often and prescribed when the faradic excitability of the muscles in relatively fresh cases had been preserved. Galvanization was indicated with slight pains.

If the suture had been performed with significant tension on the nerve, then warm baths and careful massage could be applied relatively soon. However, exercise of the injured extremity had to wait for up to 2-3 weeks, also beginning electrization by this time. In these cases, it was especially recommended to perform exercise of the healthy extremity to stimulate the impulse in the injured extremity by the repercussion method.

It is especially difficult to perform physiotherapeutic measures with the application of massive plaster bandages and with flexion or extension in the joints. In these cases, massage and light exercise of the injured extremity could practically only be begun after the bandages which permanently fix the extremity are replaced by removable light splints. It is important to stress that in such cases the presence of a splint which fixes a certain position of the extremity does not contradict the application of physio- and mechanotherapy.

It is specifically in these cases with the late application of physio- and mechanotherapy that stable pictures of secondary arthrogenic and myogenic contractures arose. The treatment of these presented considerable difficulties, sometimes requiring additional operations on the joints, muscles, tendons, with a subsequent prolonged period of treatment by physical methods. The skilled combination of extremity fixation with movement is the ideal course of treatment after operations on the peripheral nervous system. Therefore, organizationally in order to avoid a series of complications, it is particularly necessary to closely tie the work of the neurosurgeon with that of the physiotherapist, which was observed in most /323 evacuation hospitals and specialized neurosurgical institutions.

It was most difficult to perform physiotherapy with defects in the nerve trunks, particularly those replaced with a Formalin treated transplant. The basic task in transplants is to preserve the transplant as long as possible so that the nerve would have time to grow through this unique prosthesis. Physiotherapeutic procedures, which increase hyperemia, facilitate the dissolution of the transplant. Therefore, numerous clinicians and physiologists (P. K. Anokhin) are of the opinion that after transplants it is necessary to refrain from warm baths, massage, exercise, etc. for longer periods. However, a number of physiotherapists and neuropathologists (V. K. Khoroshko, O. M. Vil'chur and others) felt that neurotization takes place more rapidly if physiotherapeutic measures are performed after the transplant of Formalin treated nerves.

The question of using physiotherapy in these cases, as well as plasty using Formalin treated transplants, has not yet been conclusively answered.

One of the complications observed after operations on the peripheral nerves was the rigid-spastic condition of the musculature, most often ensuing after suture of the sciatic nerve and after combined injuries of several nerves, as well as nerves and vessels. We must assume that the dissociation in the rate of restoration of some nerves as compared with others, and particularly the non-uniformity in the regeneration of the somatic and vegetative nervous system, led to the emergence of a spastic condition of the musculature. Aside from diathermy, iontophoresis, sollux and other methods of physiotherapy, good results were obtained in these cases from bilateral lumbar block and sheath block of the extremity with intervals of 14-16 days between injections. Usually 2-3 injections were given. It must be stressed that with sheath block in these cases, usually only those muscle beds were filled with novocaine through which the operated nerves passed.

Already in relatively close periods there were sometimes noted certain defects which required minor additional surgical measures to dissect commissures between the skin and the muscles, additional tendolysis operations, sometimes tendon suture and plasty.

We must categorically reject the proposal of certain surgeons, orthopedists and traumatologists (V. D. Chaklin and G. Ye. Ostroverkhov) to perform replacement operations on tendons at the same time as nerve operations or very soon thereafter. Cases were observed when physicians' commissions proposed performing Pertes operation, i.e., transferring the pull of part of the extensors to the flexors, to patients who had been discharged from the hospital after suture application to the radial nerve after a period of 2-3 months.

End to end suture application to the radial nerve, even with transfer of the nerve to the anterior side of the brachium, gave good results in the overwhelming majority of cases. Therefore, the work of the flexors should not be reduced without particular indications, particularly since after Pertes' operation there are no fine extension movements which are especially necessary in skilled labor.

Also, according to the data from materials of personal observations, it was necessary to perform repeated operations on patients who had undergone corrective surgery on the tendons, while the basic operation on the nerve trunk had not been performed. This methodology deserves every type of criticism.

Evaluating the course of regeneration in the post-operative /324
period, it is necessary to come to the conclusion that orthopedic replacement operations should be performed only in the absence of restoration, with incomplete or pathological regeneration, with the emergence of contractures, and other pathological conditions.

Orthopedic operations must be performed at the moment of nerve operation in those cases where there is no hope of subsequent restoration of the nerve trunk due to a very large defect, severe bone and joint deformations, etc.

However, in the post-operative period, the question of further ambulatory or repeated stationary treatment of the patient is usually solved. In cases of trauma to the trunks of the radial and tibial nerve, the patient was discharged with a light removable splint which corrected the pathological position well, with explicit instructions on how to use the splint. The patient was directed to ambulatory treatment.

The modern connection of out-patient clinics and polyclinics under peacetime conditions facilitates the observation of wounded patients with injuries to the peripheral nerves.

In a number of cases, repeated hospitalization of the patients was necessary after operations on the nerves in order to determine the character of regeneration (pathological regeneration) and to clarify the indications for later additional operative interventions on the nerves, on the tendons, sometimes on the bones, vessels, vegetative conductors, ganglia and joints.

## CHAPTER IV /325

## FIREARMS INJURIES OF THE INTERCOSTAL NERVES AND THE THORACOABDOMINAL NERVE

The intercostal nerves are the anterior branches of the thoracic nerves, which originate from the first to the twelfth thoracic segment of the spinal cord. They are located in close proximity with the artery and vein of the same name and comprise together with them the intercostal neurovascular fascicle. In injuries they are often damaged simultaneously. The elements of the fascicle at first (to the median axillary line) located rather compactly in the following order downward: the vein, the artery, and the nerve. The fascicle lies in the groove (sulcus costalis) on the inferior-internal surface of the rib and is to a considerable degree protected during injuries of the actual intercostum (soft tissues). Anterior to the axillary line, the intercostal artery, as well as the nerve, come out into the intercostal space and therefore are more vulnerable.

The intercostal nerves at the beginning (in the back) are covered from the inside with only a thin layer of fascia and pleura. Therefore they may be involved in the process during inflammation of the pleura, during its commissures and fusion, as well as during injuries. Subsequently the intercostal nerve passes between the external and internal intercostal muscles.

The locomotory muscle fibers from the six superior intercostal nerves innervate the muscles of the chest, which participate in respiratory movements, while the muscle branches of the six lower intercostal nerves innervate the muscles of the

prelum abdominale. The six lower intercostal nerves are located in the abdominal wall between the internal oblique and transverse muscles.

The sensory fibers of the intercostal nerves innervate the skin on the lateral and anterior surface of the chest. Branches from the II and III intercostal nerve, merging, form the n. intercosto-brachialis, anastomizing with the internal cutaneous nerve of the brachium (maybe also of the forearm). We will have to refer to these connections later in explaining certain types of irradiating pains in injuries to the intercostal nerves.

Also diverging from the intercostal nerves are the pleural and abdominal sensory branches, which innervate the pleura of the thoracic wall and diaphragm, as well as the peritoneum of the anterior-lateral abdominal wall and diaphragm.

It is assumed that with closed injuries (most often with rib fractures), intercostal neuralgia occurs easily (due to the proximity of the intercostal nerve to the rib in whose sulcus the nerve is located). However, experience shows that pains which are actually frequent and intensive in closed rib fractures have a local character, do not give encircling irradiation toward the front, and are not accompanied by /326 disruption in nerve fiber conductivity (sensitivity disorders, weakening of the abdominal reflexes, etc.). Therefore it is more accurate that these pains arise due to the periosteum, the pleura, i.e., local irritation of the sensory receptors and nerve branchings in the tissues.

Establishing the frequency of firearms injuries to the intercostal nerves during the period of the Great Patriotic War is not an easy task if only because in the overwhelming

majority of cases, injury to these nerves associated with penetrating wounds to the chest and abdominal cavities is of secondary importance as compared with the basic cavity wound and is by far not always registered.

According to the materials for the development of illness histories, injuries to the intercostal nerves comprised 0.04% of all wounds to the peripheral nervous system.

However, in special sections and in hospitals for patients with chest wounds it was possible to establish that wounds to the intercostal nerves were quite frequent. In one such evacuation hospital, of 500 patients examined (for various reasons), 72 had some degree of intercostal nerve injury. This comprises around 2.0% of the overall number of those wounded in the chest who were under our observation. Many patients were not included in this number,since the symptoms of intercostal nerve injuries were insignificant in them. If, moreover, we consider that a significant number of injuries to the intercostal nerves accompanying the basic wound may be found also with a special neurological examination of all those patients wounded in the abdominal cavity, then it becomes clear that injuries to the intercostal nerves are encountered with injuries to the chest and the abdominal cavity quite frequently, but less often than injuries to the peripheral nerve trunks with wounds to the extremities. However, even this small percent (2.0) must give a rather significant number of injuries to the intercostal nerves if we consider the fact that chest wounds comprised from 6.0 to 10.0% of all wounds during the First World War, while in the period of the Great Patriotic War this percentage was lower (Yu. Yu. Dzhanelidze). Evidently, the same may be said also regarding wounds to the abdominal cavity. The reduction in the frequency of injuries to the intercostal nerve is explained in a certain measure by the fact that part of it is located behind the rib, which is why the nerve may remain

undamaged with passage of a foreign body through the intercostal space. This assumption is confirmed by the data of our personal observations. Of 72 wounded patients, 34 had damage to the intercostal nerve after their injury. Of these 34, only 6 had injury to only the soft tissues, while the remaining 28 suffered rib damage.

Thus, firearms wounds of the intercostal nerves often accompanied rib fractures. Moreover, injuries to the intercostal nerves occured not only as a result of firearms wounds and their complications, but also as a result of operative interventions associated with rib resection. Thus, according to our data, traumas to the intercostal nerves resulting from direct wounds sustained were noted in 34 cases, while those resulting from operative intervention -- in 38 cases. On the basis of these same data it was possible to isolate a number of reasons leading to injuries of the intercostal and thoraco-abdominal nerve (table 27).

The significance of rib damage in injuries to the intercostal nerves is evident from table 27.

Injury to the intercostal nerves with wounds to the soft tissues was noted in 8.3% of the cases, and with wounds to the ribs -- in 38.9% of the cases. From one to six ribs /327 were damaged in these cases: one rib -- in 22 patients, two -- in 20, three -- in 16, four -- in 4, five ribs -- in one patient, and finally, six ribs -- in 3 patients.

Injuries to the ribs were either a consequence of the wound, or the ribs were resectioned in operations performed due to empyema, removal of foreign bodies, and thoracoplasty with a residual cavity or thoraco-bronchial fistulas.

Table 27

Distribution of injuries to the intercostal nerves depending on the character of their injury

| Character of the injury | Percent |
|---|---|
| Injury to soft tissues..... | 8.3 |
| Rib fractures..... | 16.7 |
| Pressure of a foreign body with rib fracture..... | 22.2 |
| Rib resection: due to osteomyelitis..... | 2.8 |
| " " removal of foreign body.... | 2.8 |
| with thoracoplasty..... | 12.5 |
| due to empyema..... | 34.7 |

Bullet wounds were noted in 21 cases, fragment -- in 51. Blind wounds prevailed sharply -- there were 69 of them, while there were only 9 open wounds.

A directly adjoining foreign body and the irritation of the intercostal nerve which it entails was observed relatively rarely.

Irritation and disruption in the nerve conductivity by a foreign body may be conditioned not only by compression of the nerve. Sometimes the introduction of metallic dust, small fragments and even pieces of cloth (clothing) into the nerve trunk are observed.

The relative rarity of direct pressure by a fragment or a bullet on the intercostal nerve is indicated by the materials of A. S. Kuznetsova, according to which out of 84 cases of foreign bodies operatively removed from various sections of the chest cavity, in only 9 cases did the foreign body directly adjoin the intercostal nerve.

In a certain part of the cases, the factor irritating and damaging the intercostal nerve is fragments of a damaged rib or a bone callous. Sometimes intercostal neuralgie was dependent on a neuroma in the central nerve segment, which most often arose with an unavoidable nerve resection in operations associated with rib resection. The most frequent reason for irritation and disruption in the conductivity of the intercostal nerve are undoubtedly cicatrical fusions and commissures which often completely enclose the nerve and cause not only pains, but also "suffocation" of the nerve with subsequent degeneration of its fibers. The presence of a long-term suppurative process in the emergence of such frequent complications of penetrating chest wounds as pulmonary empyema, thoraco-bronchial fistulas and osteomyelitis of the ribs conditioned the development of thick pleural layers, fusions and commissures with the surrounding tissues in which the intercostal nerve often became involved although it had not been damaged. This "fused block" in which the nerve was involved depended most often on empyema, in which encased fascicles of nerve fibers were found among the scar tissue (A. T. Khazanov).

Finally, the group of injuries to the intercostal nerves /328 which arise sometimes as a result of operative interventions is deserving of attention.

It is difficult to require from the surgeon a careful attitude toward the intercostal nerve during preliminary wound treatment and during suture application with an open pneumothorax (at the early stages of rendering medical aid), and this is practically unfeasible. However, there is no doubt that in planned operation it is necessary to first isolate the intercostal nerve from the neurovascular fascicle before application of a ligature to the fessels. This is often difficult, and with a strong adhesion process may even be impossible.

As early as 1934, V. M. Mysh focused the attention of surgeons on the possibility of emergence of severe intercostal neuralgia resulting from ligation of the intercostal nerve simultaneously with the vessel, as sometimes happens, for example, during appendectomy from a pararectal incision or during kidney operations.

The very intersection (resection) of the intercostal nerve, which is sometimes unavoidable in operations performed on the chest, should be done precisely whenever possible to avoid the formation of a central neuroma which might be a source of severe neuralgia. However, it is better to avoid resection of the intercostal nerve whenever possible. "Excess damage to these nerves (during rib resections to remove foreign bodies from the chest cavity) is important to avoid whenever possible, which in most cases is fully attainable" (Yu. Yu. Dzhanelidzye).

Symptoms of the injury of the intercostal nerves are: pain and paresthesia, disruption in cutaneous sensitivity, changes in the abdominal reflexes, paralyses and pareses of the abdominal wall muscles. The latter two symptoms, obviously, are evident only in injuries to the lower intercostal nerves (VII - XII).

According to the materials of personal observations, the following symptoms were distributed as follows in 72 patients: pains were observed in 66 patients, of which 32 exhibited pains of an irradiating character; sensitivity disruption was evident in 49 patients: of the anesthesia type -- in 18 patients, hypesthesia -- in 26, and hyperesthesia -- in 5. Changes in abdominal reflexes were noted in 41 out of 65 patients with injuries at the level of the sixth-twelfth thoracic segment.

Hernias of the abdominal wall were noted in 11 patients out of 32 with injuries at the level of the seventh-twelfth segment.

Pains were the most frequent symptom. They occur much more frequently as a result of nerve compression and its involvement into the cicatrical process, and less often with complete intersection of the nerve (in the latter case due to the formation of a neuroma in the central segment). Spontaneous pains were noted rarely, and were must more often reactive -- during inhalation, coughing, sneezing, turning, straining, physical tension, or pressure on the intercostal cpace.

The pains bore a sharp, stabbing, pulling character and were sometimes of extreme intensity. Their encircling character was typical (irradiation to the chest or midline of the stomach). However, the irradiating character of pains was not observed in all cases. With acute manifestations of the irritation, sometimes soreness was noted during tapping along the spinous processes of the vertebrae corresponding to the level of injury of the intercostal nerve.

Comprising a special category were pains irradiating into the arm on the side of the chest wound. They were sometimes noted by patients with manifestations of irritation in the I-III intercostal nerve. These pains irradiated into the /329 area of the internal surface of the upper extremity, into the zone of innervation of the cutaneous nerves of the brachium and the forearm. Irradiating pains in the forearm were sometimes noted with irritation of the diaphragmal sensory receptors by a foreign body close to the diaphragm or in cases of pleurodiaphragmal fusions.

It is not always easy to distinguish pains which are dependent on irritation of the intercostal nerve or its branches

from pleural, pleuro-diaphragmal or pleuro-pericardial pains. Speaking in favor of injury to the intercostal nerve is the irradiating character of the pains, often soreness during palpation along the course of the nerve in the intercostal space, and the presence in a number of cases not only of pains, but also other symptoms of its injury (disruption of cutaneous sensitivity, changes in abdominal reflexes, paresis of the abdominal wall muscles).

Sensitivity disruptions are the second most frequent symptom. The zones of disruption are determined by the level and number of the injured intercostal nerves. Since the posterior branches of the toracic nerves diverge in the proximal region and nerve injuries near the vertebral column are rare, most often localizing in the lateral or anterior section of the chest, sensitivity disruptions on the back, in the zone of the posterior branches, were not noted. Thus, we may speak of injury not to the thoracic, but specifically to the intercostal nerves.

Zones of disrupted sensitivity were noted on the anterior-lateral (with localization of the injury proximally of the divergence of the lateral branches) or anterior (with more distal localization) surface of the torso and were located in strips. Their width depended on the number of damaged nerves and was, obviously, always less than the zone of innervation of the afflicted territories (due to coverage by neighboring healthy superior and inferior intercostal nerves).

As a rule, the zones of anesthesia and hypesthesia did not reach the midline (from the front) by 1 - 1.5 cm due to coverage by the nerves of the opposite side. However, in the presence of hyperesthesia, due to the same anatomical relations, the zone of hyperesthesia passed over the midline to the healthy side by the same 1 - 1.5 cm.

Paralysis and paresis of the abdominal wall muscles was observed in injuries to the VII - XII intercostal nerves. According to the materials of personal observations, of 32 wounded patients with injuries to the inferior thoracic intercostal nerves, 11 exhibited paretic diverticulum of the wall, for which the injury of at least three neighboring nerves is necessary. During "straining" of the patient or coughing, there was a prominance of the abdominal wall, most often limited at the top by the lower edge of the costal arch, at the bottom -- by the Poupart's ligament, medially -- by the external edge of the musculus rectus abdominis, and laterally -- by the external edge of the musculus quadratus lumborum. The absense of protrusion in the area of the rectus muscle may be explained by the presence of strong aponeurotic extensions in which this muscle is enclosed and which are sufficiently tightened, as well as by the numerous loop-shaped anastomoses between the muscular nerves of the anterior branches of the intercostal nerves coming up to the musculus rectus.

Considerable protrusion was noted with lower ($D_8$-$D_{11}$) nerve injuries (no less than 3-4). If nerves $D_6$-$D_8$ or $D_7$-$D_8$ were injured, then the protrusion was noted only in the upper region of the abdominal wall.

Changes in the abdominal reflexes were understandably /330 noted again with injury to the inferior intercostal nerves. It turns out that this symptom is finer then the disruption of sensitivity or paresis of the abdominal wall muscles. Thus, in individual cases a clear reduction in the corresponding abdominal reflex was noted with injury to even a single intercostal nerve. With injury to two neighboring nerves, the reduction or even loss of the reflex at the corresponding level was already the rule. It should be noted that not

only the seventh and eighth thoracic segments, but also the sixth have a significant importance in determining the upper abdominal reflex. In a number of patients whose lowest injured intercostal nerve was the VI nerve there was already an apparent reduction in the upper abdominal reflex.

However, injury to no less than 3-4 intercostal nerves turned out to be necessary in order to weaken the deep (tendinous) abdominal reflexes. This may be explained by the fact that all the muscles of the half of the abdominal press innervated by the segments $D_7$ to $D_{12}$ participate in the locomotory "response" of the given reflex. With such mass contraction, the loss of innervation of one or two segments was evidently insufficient.

The injury to one intercostal nerve was expressed only in the presence of its irritation in the form of pains, soreness of the nerve under pressure, and sometimes by a narrow band of hyperesthesia. There were no manifestations of loss with complete severance of a single nerve (except for the reduction in individual cases of the corresponding abdominal reflex, as was noted above). This is understandable, since the individual segmental cutaneous and muscular regions are not strictly separated from one another.

Of the disorders noted above, the most difficult for the patient were the pains, which sometimes reached extreme intensity. They could disrupt sleep, hinder movements and breathing. Having recovered from the primary illness, the patient sometimes nevertheless remained limited as to his work capacity and combat fitness.

Involvement of the nerve into the scar was the reason for pains more often than a neuroma of the central segment.

In the first cases, the neurolysis operation was naturally performed to eliminate the pains. However, this operation in practice could often not be performed. The nerve was so tightly and closely fused into the scar and the pleural adhesions that it was impossible to isolate. Therefore it was often necessary to intersect the intercostal nerve above the point of its injury. In the presence of pains conditioned by a neuroma, the introduction of novocains or alcohol into the nerve or its resection above (proximally) the neuroma (for example, paravertebrally) could be recommended. Of the physiotherapeutic methods, anode-galvanization and UHF therapy could be tried before resorting to the named measures. However, these usually had little effect.

Among the number of disorders which disrupt the physical work capacity of the patient is the significant paresis of the abdominal press muscles. The girdle-bandages used in these cases are uncomfortable and cumbersome to the patient.

Another group of disorders accompanying penetrating chest wounds are injuries to the diaphragmal nerve.

It is considered that direct firearms injuries of this nerve are rarely observed due to its "protected position". This may be true, since the clinical pictures of total paralysis of the thoraco-abdominal nerve with the typical high placement of the diaphragm cupola and paradoxal movement during inhalation were not observed in wounded patients. In part this may be somewhat strange, since the considerable extent of the /331 thoraco-abdominal nerve on its way to the chest cavity, its location in the anterior midwall between the pericardium and the mediastinal pleura, where foreign bodies are often localized and where pleuro-pericardial adhesions often arise, could, it seems, condition its injury. In actuality, while cases of paralysis of the thoraco-abdominal nerve were not observed, the symptoms of its irritation were rarely noted.

These manifestations of irritation were maintained by the presence of foreign bodies and pleuro-pericardial or pleuro-diaphragmal adhesions observed in 9 patients. The cardinal symptom in these cases was dyspnea. As a rule, it was not observed in a state of rest, but was manifested during movement and even during insignificant tension, although very rarely. Vasomotor phenomena (cyanosis, elevated blood pressure), as well as perspiration, which are also considered characteristic for injury (irritation) of the thoraco-abdominal nerve are reflex disorders which arise as a result of the close anatomical and functional connections of the thoraco-abdominal nerve with the sympathetic endings. This is the reason for the emergence of such remote and siffuse reflex sympathetic phenomena as perspiration and elevated blood pressure. Perspiration, which occurred only after injury, was noted in 2 patients with irritation of the thoraco-abdominal nerve. Two patients exhibited elevation of blood pressure to 145/95 and 170/110 mm hg column. Cyanosis was noted in 3 patients. Aside from dyspnea, a constant symptom was the manifestation of pain. Here it was not so much the intensity of the pain that was typical, as its irradiation and diffusion: typical projections were noted into the upper arm, clavicle, neck, and sometimes the mastoid process. The intensification of the pains was quite regularly observed during coughing and straining. Sometimes soreness was noted during pressure in the region of the scalene muscle and forward of the sternocleidomastoid muscle. None of these patients suffered from hiccups.

## CHAPTER V

## CONSERVATIVE TREATMENT OF FIREARMS INJURIES TO THE PERIPHERAL NERVES

### Conservative treatment of firearms injuries to the nerve trunks

The goal of treating firearms injuries to the peripheral nerves is the creation of conditions facilitating the restoration of the disrupted functions of the organism and the acceleration of regeneration of the damaged nerve. /332

Before the First World War, the prevailing viewpoint was that operative intervention was considered indicated only in those cases when conservative methods of treatment (heat, cold, cantharides, narcotic substances, electrization, massage, blue light, baths) were ineffective.

The proponents of this view based their ideas on the fact that long-term conservative treatment makes it possible to establish a precise diagnosis with a greater degree of certainty and that in the greatest percentage (over 50) of cases a cure may be achieved by the application of physical treatment methods along, which was indicated by N. I. Pirogov in his time. In connection with this viewpoint, before 1914 operations on the peripheral nervous system were performed extremely rarely, and only after all other treatment methods, particularly physiotherapy, had been exhausted without result.

With the appearance of a large number of wounded with injuries to the peripheral nerves in the period of World War I

who were in need of rapid and complete treatment methods, conservative treatment faded into the background and numerous proponents of early operation appeared. However, even at this stage, the fear of infection and complications often necessitated postponing the operation for a period of 3-4 months after wound healing and performing conservative treatment during this period.

With the introduction of electrodiagnostics into practice, the view was established that with absence of a degenerative reaction, only conservative treatment was indicated, while in cases where there is a degenerative reaction it is expedient to wait 3-6 months and then to operate only in those cases when there are no signs of restored function during this period.

Based on the teachings of I. P. Pavlov on the wholeness of the organism, its oneness with the external environment, as well as I. P. Pavlov's conceptions on neurism with the predominant role of the cerebral cortex, which determines the interconnection of all phenomena within the organism and the interrelationship of the organism with the external environment, it is impossible to divide the treatment of firearms injuries to the peripheral nerves into conservative and operative.

Conservative treatment during the Great Patriotic War /333
was performed on all wounded patients with firearms injuries to the peripheral nerves, without exception. In part of the patients, who were not subject to operation, the conservative method was the only one providing maximal therapeutic effect. In all other patients, for whom operations were performed,

conservative treatment was a mandatory component part of the complex of treatment measures performed before and after the operative treatment. Thus, in speaking of the treatment of firearms injuries to the peripheral nerves, we are referring to conservative treatment as the singular method and as part of a complex treatment -- operation and conservative treatment.

The literature on the treatment of peripheral nerve injuries is extensive, but only the surgical part of the complex treatment for these disorders has been worked out in greatest detail. There is a large number of experimental and clinical works substantiating the application of physiotherapy, balneotherapy, exercise therapy and massage in peripheral nerve injuries. However, different authors obtain different results with the conservative treatment of firearms injuries to the peripheral nerves. The therapeutic effect from the application of certain physical agents, balenotherapy and exercise therapy in a significant number of cases does not reach the level we might expect based on the theoretical data on the physiological action of these agents.

The reason for this is that various authors often cite only the symptomatic conservative therapy which is either not pathogenetic at all, or is only partially so.

It is necessary to constantly keep in mind the determination of the human organism given by I. P. Pavlov: "Our system is to the highest degree self regenerating, self maintaining, self restoring, self repairing, even self perfecting. The most primary, strongest and constantly remaining impression of the study of the higher nervous activity by our method is the exceptional plasticity of this activity, its tremendous

capacity; Nothing remains immobile, impliable, and everything can always be achieved, may change for the better if only the appropriate conditions are present".

We must consider the fact that various forms of activity of the organs, tissues and systems of an organism are determined not only by the force, character and form of the stimuli used, but to the same degree also by the change in the functional condition of the organism's organs and tissues themselves. It is also necessary to remember that mechanisms regulating the activity of various organs and tissues are determined not only exclusively by certain specific properties of the nervous system and humoral factors, but also by the organs and tissues themselves.

The teaching of I. P. Pavlov on higher nervous activity, and the works of K. M. Bykov on the cortico-visceral interrelations are a sufficient substantiation for the position that the leading role in the restoration of various functional disorders belongs to the nervous system, and primarily to the cerebral cortex.

The concept of pathogenesis is inseparable from the concept of general and local reactivity of the organism. Therefore, therapy must be directed primarily at the restoration of normal reactivity of the organism. It is only in way that the constructed therapy will be rational and will /334 yield the proper effect.

The works of A. Ye. Shcherbak, S. A. Brushteyn, V. K. Khoroshko, A. V. Rakhmanov, as well as precisely established and tested clinical facts have shown that physical agents may assist in the implementation of restored function of the nervous system and may affect various elements in the complex reflex mechanism chain.

In developing a treatment methodology, it is necessary to clarify the entire multiplicity of phenomena arising in the organism. It is necessary to examine all the symptomatics characteristic for injury to the peripheral nervous system, considering its effect on the organism and the disruptions in functions of various systems which it causes.

The clinical picture of firearms wounds to the peripheral nerves is distinguished by its great polymorphism. However, part of the symptoms have not yet been clarified from the standpoint of their pathogenesis. Aside from the changes at the point of injury as well as in the muscles, tendons, bones and skin which are deprived of innervation or found under conditions of distorted innervation, there are also changes in the segmental centers. Functional shifts also arise on the part of the somatic and vegetative centers in the brain.

On the basis of a physiological and morphological evaluation, injury to the peripheral nerve must be viewed as a partial expression of the trauma to the central nervous system which is unavoidable in this case. This viewpoint has already long ago been presented by M. I. Astvatsaturov, B. A. Favorskiy and others. However, all the symptoms of loss in this case were incorrectly classified as reflex paralyses, which made it difficult to establish the true pathogenesis of these losses. "The loss of function after peripheral nerve injury cannot be called reflex simply because it is conditioned by central causes. In actuality the fact is that with a particular form of nerve injury there arises a functional and destructive defect in the nerve centers, which is already a secondary hindrance to the implementation of the reflex functions" (P. K. Anokhin).

The most important pathogenetic trait in the peripheral nerve injury is the summation of the indicators of loss resulting from the severance of nerve conductors with the indicators of loss in the nerve centers. The physiological reason for one process and the other, in the opinion of P. K. Anokhin, is different, but they are manifested on the same peripheral organ -- the extremity.

P. K. Anokhin calls the loss of function in the zone of the injured nerve resulting from severance of its fibers "the peripheral component of trauma". However, these preliminary losses for the most part are accompanied by losses and irritations of a central origin. This is the "central component" of the peripheral nerve trauma.

In almost all cases of injuries to the peripheral nervous system, the clinical status is a summary including both components. Thus, the clinical symptomatics of peripheral nerve injuries is comprised of local centralized symptoms and of remote repercussive symptoms.

Observations of 350 wounded patients with firearms injuries to the peripheral nerves dynamically conducted by Ye. A. Zakharova allow us to conclude that in 90.0% of the cases there were disruptions in peripheral blood circulation of a character reducing blood supply to the tissues. These /335 disruptions are conditioned by a sharp increase in the tonus of the arterial wall. It is necessary to stress the fact that in most cases the disruptions in tonus bore a generalized character, but the most clearly expressed disruptions were observed on the injured extremity.

The degree of artery tonus disruptions is not associated

with the injury of one nerve trunk or another which may be more or less rich in vegetative inclusions, but is in a certain dependence on the duration of the pathological process. Disruptions in vascular tonus are quite stable, and in the course of a prescribed treatment which gives favorable clinical effect, restoration is observed, although as a rule it is not significant.

As evidenced by a number of studies, thermal stimulators, sulfurated hydrogen baths, exercise therapy and massage cause in some cases an inverted vascular reaction which is expressed in increased arterial tonus which subsequently turns into a physiological reaction. These changes in the peripheral blood circulation may be used as a test for selecting the most rational combinations of methodologies of complex treatment at various stages of the pathological process.

I. Ye. Stezhenskiy and N. A. Kaplun performed special studies on the condition of the active mesenchyme in firearms nerve injuries. In the overwhelming majority of cases, they were able to establish a reduction in the activity of the elements of cutaneous mesenchyme on the afflicted side. Less expressed changes were found also on the healthy side. The most acute shifts were found with traumatic neuritis with causalgic syndrome. It is also necessary to stress at this point that these changes in the active mesenchyme are associated not with the localization of the process, but with its character.

Ye.B. Morkovnikova studied the ketoacidic metabolism in patients with firearms injuries to the peripheral nerves and with the presence of pain syndrome. R. S. Faynberg studied the changes in the biochemical indicators in the blood of these patients. They were able to establish that in the overwhelming

majority of cases of peripheral nerve injuries, along with vegetative asymmetries there is also biochemical asymmetry (reduction in the content of sugar, the amount of protein, albumins, increase in the amount of globulins), and in the presence of pain syndrome there is a disruption in the keto-acidic metabolism characteristic for $B_1$-hypovitaminosis.

The presence of a central component in cases of injuries to the peripheral neuron is confirmed by the results of studies of electroexcitability and biological reactions of the skin to ultraviolet irradiation in this category of patients.

N. M. Liventsev, who performed a systematic study of electro-excitability on a large number (over 300) wounded patients, established that in a great majority of firearms nerve injuries there is noted a change in the electroexcitability of the areas neighboring the injured nerve which have not been directly involved in the trauma. In singular cases, changes in the electroexcitability of a nerve in a symmetrical healthy extremity are noted.

G. S. Varshaver, O. M. Vil'chur and Ye. I. Mazel' studied the reaction of the skin to ultraviolet radiation (with the full spectrum and its individual components) in injuries to the peripheral nerves and to the central nervous system. As a result of this work it was established that in firearms injuries to the peripheral nerves there are a number of specifics in the photosensitivity of various areas of the skin which enter into the innervation of the injured nerve. This fact confirms to a certain degree the position also presented by /336 other authors that photoerythema is a process controlled not only by the peripheral, but also by the central nervous system.

The results of these special studies in patients with firearms injuries to the peripheral nerves, as well as a detailed study of the individual symptoms of the complex syndrome of nerve injury to a certain degree expand our understanding of the pathogenesis of the given illness and indicate means of complex therapy, particularly physiotherapy, balneotherapy and exercise therapy, which should be viewed not only from the standpoint of local effect, but also of their influence on the entire organism, including the nerve centers.

Complex treatment should be viewed not as a sum of methods, but as a successive effect on the various functions of the injured organism at various stages of development of the pathological process. The various methods of complex conservative therapy (physio-balneotherapy, exercise therapy, massage, work therapy, diet therapy and medicinal treatment) in various combinations and sequences must be used in every individual case depending on the specifics of the process and the overall condition of the organism.

## Substantiations for the methodology of physiotherapy, balneotherapy, exercise therapy and work therapy

Patients who have sustained injuries to the peripheral nervous system must be under the constant observation of a neuropathologist and surgeon. Excess conservatism here is obviously inadmissible. However, observations show that, aside from cases in which restoration of function proceeds rapidly under the influence of conservative treatment, as well as cases in which operative treatment is counterindicated (ulceration which does not heal for a long time, severe osteomyelitis, multiple injuries, etc.), and even in cases where there are indicators for operation, there is no singular opinion on the time of operative intervention (there are still numerous proponents of prolonged, 4-5 month conservative treatment). Even

most proponents of early operative intervention recommend that the operation be performed 4-5 weeks after healing of the wound. The complex character of firearms wounds to the peripheral nerves makes the application of primary suture impossible in most cases.

Thus, in the overwhelming majority of cases, as evidenced by the experience of the Great Patriotic War, injuries to the nerve trunks become the object of operative intervention a considerable period later after the wound is sustained. Moreover, in many cases of firearms wounds to the peripheral nerves there are combined injuries to the vessels, bones and nerves. According to the materials for the development of illness histories, a large number of wound cases with injury to the peripheral nerves (41.5%) were fragmentary. According to these data, they were tangential in only 3.2% of the cases, and in the rest they were open and closed. This character of injury explains the fact that most wounds to the extremities with nerve trunk injury are of considerable size, which leads to the formation of large, rough scars. The initial crushing of tissues with hemorrhaging conditions the involvement of the nerve trunk into the cicatrical process for a considerable extent.

Clinical observations have shown that firearms injuries /337 to the nerve trunks are always complicated by infection to one degree or another. Complex biochemical and infectious processes arise in the wound. Their zone of influence is not limited to the localized injury, but always has a tendency to spread. Exoneural as well as endoneural scars develop as a result of these complex processes. At that moment, when in the zone of injury there ensues relative well-being and the scar formation process is concluded, in other areas of the complex system of extremity innervation there are still observed diminishing processes after the products of the previous infection are brought in. The observations of B. G. Yegorov in his histological

study of the sympathetic nodes extirpated due to severe causalgic manifestations serve as proof of this fact. In these nodes he found round celled infiltration and degenerative changes in the cellular elements, while the basic infectious centers had completely subsided. Finally, it is necessary to consider the fact that the picture of anatomical relations of the peripheral nerves which is complex in itself is complicated even more after extensive damage from firearms wounds.

The long-term presence of the afflicted nerve among pathologically altered tissues is not indifferent for it, and leads finally to the development of severe, often irreversible changes.

The task lies in not overlooking the nerve damage from the very first days and in creating for the nerve the same favorable conditions as for the other damaged tissues. The task of the functional restoration of the nerve cannot be put off until such time when the wound heals or almost heals. It is necessary to keep in mind that only in the early period is it possible to render a significant effect on nerve regeneration. It should also be remembered that normal regeneration and restoration of function are hindered by the inflammatory processes described above which may last for a long time, by large perivascular infiltrates and by excess development of connective tissue.

In all cases of peripheral nerve injury, conservative treatment was performed from the very first days after the wound was sustained. The goals of this treatment were: 1) to create better conditions for nerve regeneration; 2) to prevent the formation of scar tissue and to facilitate its resolution; 3) to prevent the formation of contractures and deformations; 4) to combat the pain syndrome; 5) to provide measures for improving nourishment and tonus of paralyzed muscles.

Used in solving these problems was a complex of prophylactic measures of an orthopedic character, as well as physio-balneotherapy and exercise therapy procedures.

In developing a course of treatment, clinical specifics of each case were considered, as well as the biological action of the indicated treatment factors and the stages of evacuation. The decisive role in preventing any complications and in creating favorable conditions for regeneration belonged to preliminary wound treatment, the widespread application of sulfamide preparations, and the proper immobilization of the extremity.

With firearms nerve injury, attention was given to the position of the extremity immediately after the wound was sustained. The early proper splinting protects the nerve against further trauma. Thanks to splinting, the antagonists of the paralyzed muscles were not shortened, while the paralyzed muscles were not extended. In applying a splint or sling the wounded extremity was given such a position in which active movements of the retained musculature could be performed with the greatest /338
amplitude, i.e., usually the so-called median position between flexion and extension.

With injury in the area of the brachial plexus -- the upper arm, the brachium must be elevated forward and upward, the elbow joint bent, the fingers straightened, and the thumb abducted.

With injury in the area of the brachium and the forearm and damage to the median nerve, the hand and fingers must be in a position of palmar flexion.

With injury to the radial nerve, the hand and fingers must be in a position of dorsal flexion, the thumb must be abducted. With injury to the ulnar nerve, the elbow joint must be extended, the hand and fingers -- in a position of palmar flexion. The most frequent complication in injury to nerves of the lower extremity is the formation of talipes equinus (tip foot) due to contracture of the gastrocnemius muscles. In order to avoid this, the leg must be extended at the knee, while the foot must be given a position at a right angle.

If the bones were intact, removable slings were applied. They were removed during treatment procedures and exercise therapy. Also used were various types of special prosthesis apparata whose purpose was to restore the lost functions in one form or another. In addition to these fixation apparata which were worn on the injured extremity, there were steel plates and springs which required work on the part of the healthy muscles to counteract the work of the spring. Thus, with paralysis of the radial nerve, a spring apparatus was used which was affixed to the forearm and hand. The purpose of this apparatus was to hold the hand in a constant position of extension at the radiocarpal artidulation due to the palmar tension. The antagonist flexors encountered counter-force on the part of the apparatus and maintained their physiological tonus, while the paralyzed extensors were not subjected to excess extension and suffered less atrophy than they would without the apparatus. This also prevented the development of flexional contractures and deformations of the radiocarpal articulation. In connection with the removal of the attachment points of the hand flexors, the grip was strengthened.

With injury to the cutaneous-muscular nerve and with paralysis of the biceps muscle, a fixed apparatus was used on the elbow joint with a rubber band on the palmar surface of the

apparatus. The sockets of the brachium and the forearm are connected by the elbow hinge which, due to a certain tension of the rubber, is constantly in a state of flexion. Thus, there is a passive flexion which is lost in connection with the paralysis of the biceps muscle.

With injury to the sciatic or the fibular nerve, orthopedic footwear is used with splints and a rubber or spring pull for purposes of holding the foot in a median or calcanel position, eliminating the harmful effects of the flexional musculature and preventing secondary deformation of the ankle joint. Thanks to this orthopedic footwear, the paralyzed extensors do not experience hyperextension and become atrophied to a significantly lesser degree. During the period of restoration of nerve conductivity, supported by the action of the spring, the extensors regain their lost tonus and strength in a shorter period of time.

From the very first days of nerve injury, measures were taken to ensure the fact that the replacement scar tissue is not randomly placed and, creating dynamic polarity for the cicatrizing tissue, the proper direction of regenerating fibers could be ensured.

The longitudinal application of galvanic current creates /339
the necessary dynamic polarity, and therby it is possible to achieve the proper direction of regenerating fibers. The local application of galvanic current in firearms injuries to the peripheral nerves affects also the central component of the trauma, causing changes in the actual bioelectrical currents of the tissues, the movement of ions, the change of diffusion processes, electrolysis, interpolar polarization, thermal action -- the activation of individual tissues and the entire organism.

This is why this physical agent occupies first place in the treatment of firearms injuries to the peripheral nerves.

The experimental work of I. A. Piontkovskiy on the effect of galvanic current on nerve regeneration, the observations of O. M. Vil'chur and V. K. Khoroshko on the course of latent infection, pain syndrome and trophic ulcers on a background of nerve injury under the influence of galvanic current have established that this physical agent is basic in treating peripheral nerve injuries.

According to the materials of personal observations (over 800 cases), in injuries to the peripheral nerves the most effective methodology of longitudinal galvanization was the following: the electrodes were placed one above the point of injury, and the other -- at the distal section of the extremity; the current voltage was 0.1-0.2 mA per 1 $cm^2$ of electrode surface. The procedures were performed daily. Each session lasted 25-30 minutes, and there were 40-45 sessions.

The effectiveness of conservative therapy in firearms injuries to the peripheral nerves depends not only on the methodology, but also on the times of its application. Even in those cases when the diagnosis of nerve injury is given early, therapeutic measures are put off until the inflammatory processes subside, consolidation of the bones sets in, etc. Sometimes by this time severe, often irreversible processes have set in, and the application of physiotherapy and exercise therapy which is early from the point of view of these devices is already late and does not give the necessary effect.

It is completely evident that measures in regard to the injured nerve in the first daya after the wound is sustained must, aside from their direct action on the nerve (in the sense

of its regeneration), also have a favorable effect on the healing of soft tissue wounds and on the consolidation of bones, as well as on the development and course of osteomyelitis.

The question arises in this regard: how will galvanization affect the inflammatory process, which in these cases is often acutely expressed, and how will it affect bone consolidation? Special observations performed in this regard showed a certain therapeutic effect in regard not only to the course of the nerve trunk wound process, but also in regard to bone consolidation and the inflammatory phenomena present in these cases.

A plaster bandage is not an obstacle in conducting longitudinal galvanization. Thus, a window may be made in the plaster for the upper electrode, and in the distal section there is either no plaster or, if there is plaster, a window is also made there for the electrode.

Of great significance for nerve regeneration is the condition of the mesenchyme formations and primarily the fibrous connective tissue in the wound area between the nerve ends. The presence of hematomas in the wound area as well as in the ends of the nerve trunk, extensive infiltrates, primarily of a purulent character, usually inhibit the growth of axons and the progress of Schwann cells.

It is also necessary to influence the inflammatory process, /340 which takes place in most cases in the central segment due to the almost constant infection of the wound. A number of experimental studies and the works of I. I. Grashchenkov have proven that there are manifestations of ascending neuritis in firearms injuries to the peripheral nerves. The inflammatory processes are also noted in the peripheral segment. All this

speaks of the necessity of using such physical agents which can affect the inflammatory process, facilitate resolution of the hemorrhages, hinder the formation of scar tissue, maintain rapid compaction of the scar, influence it during its period of development, and maintain more active metabolis processes within it. Indicated in this respect is the application of transverse ionization with potassium iodide, paraffin therapy, mud treatments and exercise therapy.

As we know from experimental works and as confirmed by clinical observations during the Great Patriotic War, iodine-ion galvanization gives a certain therapeutic effect, facilitating the dissolution of hemorrhages, as well as the removal of the products of disintegration and the reduction of swelling. Iodine-ion galvanization is undoubtedly an effective measure influencing the scar formation processes. This method may be used to hinder scar thickening.

Transverse ionization with potassium iodide was performed according to the following methodology: the procedures were applied every other day, alternating with longitudinal galvanization. The current voltage was 0.1-0.2 mA per 1 $cm^2$ of electrode area, the session lasted 25-30 minutes, and there were a total of 40-45 sessions.

Transverse ionization with potassium iodide was performed in the very first days after the wound was sustained, with the exception of cases of nerve injury combined with bone fracture or with vascular injury. In these cases, transverse iodine-ion galvanization was begun 12-14 days after the beginning of bone consolidation and after ligation of the vessel or suture application to it.

The advantage of paraffin therapy is that paraffin is easily sterilized, and therefore is widely used also during

the period when an open wound is present. As we know, paraffin improves the drainage of secretions, accelerates the processes of wound granulation and epithelization. Paraffin therapy has a favorable effect on the resolution of inflammatory processes which develop in the muscles, tendon sheaths, tendons and ligaments. Extravasates are dissolved more rapidly with this method of treatment, which leads to a more rapid restoration in the function of the injured nerve, especially if the reason for injury to the nerve had been hemorrhaging.

Paraffin was applied either to the entire extremity, or to the wound and the nerve segments above and below the wound. The temperature of application was 55°. Depending on the reaction it was elevated to 60-65°. The number of applications was 20-25, with each procedure lasting 30-45 minutes. The procedures were repeated every other day.

Mud therapy acts on the center as well as on the entire organism by the thermal, chemical and biological properties of the mud. The mud, which is used in direct proximity to the center of the injury, facilitates the dissolution of residual manifestations of infiltrates, hematomas, the softening of scars, as well as intensifying metabolic processes, reducing pains and accelerating the regenerative processes in the damaged tissues. It is also necessary to consider the effect of mud on the function of the skin and the endocrine-vegetative system.

Mud applications were used on the injured extremity at the place of injury -- the nerve segments lying above and below. The temperature of the mud is from 40° to 45°. The procedure /341 lasts for 20-25 minutes and is performed every other day. The total number of sessions is 20-25.

The direct application of mud to the wound surface is possible only in those cases when there is certainty that it has not been bacterially contaminated.

In performing the complex of described treatment procedures, the most effective turned out to be the following methodology: one day -- longitudinal galvanization and paraffin therapy or mud therapy, which is performed before the longitudinal galvanization; the following day -- transverse ionization with potassium iodide.

The non-complexity of the method of these procedures allowed their application in any hospital at early stages of evacuation -- an army or front line hospital.

It is known that the growth and condition of the nerve fiber depends in the greatest measure on the degree of its activity. The more impulses the nerve fiber receives from the center and the more impulses this center receives from the periphery, the more rapidly fiber growth occurs.

P. K. Anokhin showed that the function of an injured nerve to restore itself is faster the more the injured organ takes on an active working role and the richer the impulses which come from the periphery and run along this nerve to the center. Even the presence of an active adjustment and a presentation of a working periphery are strong factors orienting the growth of the nerve fibers in the necessary direction.

When left alone, muscles which are denervated or found under conditions of pathological innervation gradually atrophy, and by the time the regenerating fibers grow up to them, the atrophy may be very acute. Therefore, for purposes of assisting

the most rapid growth of the nerve fiber and restoration of its operative function, it is necessary, aside from the complex of physiotherapeutic measures and the system of active exercises, to introduce a number of work movements which bring to life the entire functional system leading to the intensification of nerve fiber growth and to the most rapid re-structuring of the nerve apparatus -- to bringing it and its surrounding pathological tissues into an active state. These exercises are particularly important in places where the nerve fibers are not severed, but merely inhibited by scars which have been fused into them. In these cases, a properly developed complex of movements frees the nerve and gives a sharp jolt toward the restoration of its function. With complete loss in function of one of the nerves, it is possible to achieve compensation of the lost function to a certain degree due to anastomoses between a healthy and injured nerve or due to the work of the muscles innervated by another nerve, or finally due to the injured muscles by means of developing non-functional additional innervation from a healthy nerve. These compensatory mechanisms may be manifested after the complex application of physiotherapy and exercise therapy.

As we know, regeneration also depends on how the replacement tissue is deposited between the nerve segments. With rest and absence of definitely directed mechanical influences, scar tissue is deposited randomly, which has an unfavorable effect on the direction of the regenerating fibers. The organizing influencing of mechanical forces on the structure of support tissue is well known.

In developing differentiated methodology of exercise therapy in firearms injuries to the peripheral nerves, the specifics of motor disruptions in this type of trauma were /342

considered. In each case, the character of disruptions in the motor function of the individual muscle groups innervated by the injured nerve, their antagonists and synergists were established, as well as the character of disruption in function of the entire injured extermity and defects in the general body posture. Such a study of the locomotory sphere of the patient makes it possible to determine hidden motor capacities and to establish true locomotory losses.

It is well known that loss of function in individual muscle groups disrupts the equilibrium of the entire locomotory system as a whole, which entails overtaxing the individual muscle groups, as a result of which the entire afflicted extremity takes on a forced, abnormal position which becomes very easily and quickly fixed. Therefore, aside from the local effect on the afflicted muscle groups, on their antagonists and synergists, active exercise was used: patients were taught to relax tense muscles and to rebuild their movements.

The basic moment of conducting exercise therapy sessions in these cases was the condition that sending impulses and training movements in the injured muscle groups take place first in the position which most greatly facilitates movement, i.e., in a horizontal plane. This eliminated the force of the extremity's weight.

When exercising the flexors and extensors of the upper and lower extremities, patients would lie on their healthy side. When exercising the muscle groups which adduct and abduct the upper and lower extremities, the patients would lie on their back.

To exclude friction from adjoining surfaces during exercise and for partial replacement of the acutely weakened function of the individual muscle groups, the therapist would support the distal section of the extremity with a loop bandage.

Weakening of the force of resistance of antagonists to injured muscles was achieved by weakening them by means of passive proximation of their attachment points. Thus, for example, with weakened dorsal flexion of the foot in connection with injury to the fibular nerve, flexion of the knee joint weakens the gastrocnemius muscle, which is the antagonist to the muscles performing dorsal flexion.

The action on the antagonists consists of weakening their tonus. Massage together with passive movements facilitated the weakening of the tense antagonists, which facilitated the subsequent work of the weakened muscles.

As noted above, all peripheral nerve injuries were accompanied by an acute disruption in peripheral blood circulation. Physical exercises of general action, as shown by the studies of V. V. Gorinevskaya, increase the flow of arterial blood to the injured extremity, even if it is not included in active work due to complete paralysis. This fact explains the circumstance that systematic application of physical exercises facilitates the equalization of asymmetry in peripheral blood circulation in traumatic neuritis.

In order for the work of the afflicted muscle groups to proceed under conditions of improved peripheral blood circulation and under a more favorable overall condition of the organism, the complex of exercises in the gymnastics therapy was constructed in such a way that the first half consisted /343 of general exercises, while exercise of the muscles affected by paresis was performed after this, in the second half of the session.

The studies of V. V. Gorinevskaya showed that this order of constructing exercise therapy sessions gave the most favorable shifts in regard to peripheral blood circulation as well as to the locomotory function of the injured extremity.

The exercise therapy sessions were conducted after thermal procedures, especially in cases of joint rigidity. In cases where massive thermal procedures were used, exercise therapy was conducted before the thermal procedures, since in the reverse order it was tiring for the patients.

In view of all the facts presented above, exercise therapy was included in the complex of treatment measures which were used from the very first days after the nerve injury. As we know, the restoration of function in peripheral nerve injuries proceeds along three routes:

1) spontaneous restoration, which occurs in those cases when as a result of the injury there is loss without severe structural changes in the cells and fibers of the peripheral neuron;

2) restoration of function resulting from the regeneration of nerve tissue;

3) in severe disruptions of nerve tissue integrity, restoration of functions is implemented by compensatory replacement, when the lost function of the injured extremity or of individual muscle groups is replaced by compensatory mechanisms.

The methodology of exercise therapy must be specific for each type of nerve injury.

Exercise therapy occupied an important place in the complex method of treating peripheral nerve injuries at any stage of evacuation of the wounded patient. As soon as the acute manifestations of the injury passed, exercise therapy was prescribed.

With the manifestation of commotion and slight contusion of the nerve accompanied by spontaneous functional restoration, the task of exercise therapy was to accelerate the restoration process. This was achieved by using active exercises of the injured extremity, particularly of the muscles innervated by the injured nerve. The amplitude of movement was gradually increased. Simultaneously with the development of active movements of the afflicted muscle, attention was given to exercise of the shoulder girdle and the cervical region of the vertebral column in nerve injuries of the upper extremity and in the lumbar region of the vertebral column -- in nerve injuries to the lower extremity. These exercises had for their purpose to increase the blood and lymph circulation in the injured extremity, to affect the cellular elements of the corresponding segments of the spinal cord. The facts presented explain the necessity and importance of including general movements in the complex of exercise therapy in cases of wounds to the extremities.

To accelerate the regeneration processes, exercise therapy was constructed according to the following plan. First the general exercises described above were performed, whose purpose was to affect the entire peripheral neuron. Then, by means of active and passive movements and various exercises, the peripheral nerve segment was stimulated from the periphery.

The studies of academician A. D. Speranskiy and his colleagues showed that the peripheral nerve segment continues to be viable after severance not only in the sense of retaining its specific properties of nerve conductivity and excitability, but also in the sense of its effect on the tissues with which it is connected. These facts indicate that the peripheral /344 segment plays not only a passive, but also an active role in the process of regeneration. Active movements of the muscles

innervated by the retained nerves transmit impulses through overlapping coverage and nerve anastomoses into the peripheral nerve segment, and thereby possible stimulate the restoration of function of the afflicted muscles. Thus, for example, in injury to the median nerve with total paralysis of the muscles which it innervates, it is necessary to use the movements of muscles innervated by the ulnar and radial nerve in order to transmit impulses through the nerve endings in these muscles through the overlapping nerve coverage into the peripheral segment of the median nerve.

As we know, in ontogenesis, the work of the muscle influences the organization of the innervation process. From this point of view, the work of the muscle with a damaged nerve is an important factor in its regeneration. The possibility cannot be excluded that the muscle itself to a certain degree orients the growth of the nerve fibers in a certain direction. In order to intensity the effect of the muscles on the regeneration process, a great variation of passive movements of the injured nerve muscle was used, as well as the sending of impulses to the afflicted muscles.

If regeneration of the nerve proceeds very slowly or the restoration of motor functions of the extremity is impossible by means of direct regeneration, the question of compensatory mechanisms arises. In these cases it was necessary to develop groups of muscles which had a similar or almost similar function to that of the destroyed muscle. For example, with injury to the median nerve, the ulnar flexor of the hand, the muscle adducting the thumb, the deep digital flexor innervated by the ulnar nerve are used.

Repercussive phenomena were also used in the restoration of functinn. The constant stimulation of cells on one side of the spinal cord is transmitted to the other side. In practice

this was utilized as follows: the healthy extremity performed a series of movements which were insufficiently or not at all performed by the damaged extremity. Then the damaged extremity performs first slight, and then ever greater movements of the same character.

Electrogymnastics of muscles has a great significance for retaining the functional capacity of muscles during that period when they are deprived of motor innervation due to nerve damage. Electrogymnastics activates the metabolism, as well as facilitating the retention of the capacity for muscle excitability. This method may be used to counteract the process of muscle degeneration which arises with nerve damage, and to partially preserve the viability of the muscles until the time of nerve restoration.

The basic, most widespread, methods of electrogymnastics are rhythmic faradization and galvanization. However, these methods already do not satisfy the requirements of modern neurological clinical practice. Rhythmic faradization gives a physiological tetanic contraction of the muscles, but it may be used only in those cases where the faradic excitibility of the muscle has been retained. Rhythmic galvanization, although it may be used in disruption of nerve conductivity, it gives only singular contractions which are non-physiological for the muscle. This is why the efforts of modern physical therapists have been directed toward finding a type of current for muscle electrogymnastics which would correspond to the changing electro-excitability of the muscles with various forms of damage to their innervation and would ensure the possibility of obtaining painless tetanic contraction. This type of current could /345 ensure maximal selectivity in regard to stimulation of the afflicted muscles without transfer of the stimulation to neighboring healthy muscles.

It has been experimentally established that for a denervated muscle the threshold of excitation by exponentially increasing impulses of galvanic current is lower than by square-wave current. Therefore, exponentially increasing impulses of various duration make it possible to stimulate only the injured muscles with a high degree of selectivity. This is the basic advantage of using pulse currents for electrodiagnostics and electrogymnastics of muscles.

The experimental-clinical studies of N. M. Liventsev have established the following.

1. Pulse currents modified by faradic and modulated faradic current may be used with certain effect for electrodiagnostics and electrogymnastics of muscles, since with their help it is possible to obtain: a) for electrodiagnostics -- data on the state of excitability of the muscle in respect to the pulse duration to which the latter respond; this makes it possible to judge the course of the pathological process within them; b) for electrogymnastics of muscles -- the possibility of isolated exercise of the injured muscles with physiological tetanic contraction.

2. The application of pulse currents in the presence of minimal active movements makes it possible to introduce into practice a new type of electrogymnastics -- "active electrogymnastics", which considerable increases the effectiveness of electrogymnastics in regard to restoring active movements.

Active electrogymnastics is the name for the method whose principle consists of using electrical stimulation of muscles as active exercise inctead of a passive rhythmic procedure when minimal active movements are retained. This must be accompanied by willed impulse and efforts at active movement. Electrical stimulation is used to increase the amplitude and force of the latter.

The substantiation for the method of active electrogymnastics is the fact that in the given case, aside from the effect of electrical current of a certain form on the muscle, a series of efferent (willed impulse and efforts at movement) and afferent (visibility and sensation of the completed movement) impulses is evoked, which facilitates the restoration of the nerve function and its regeneration (P. K. Anokhin).

Electrogymnastics with faradic current was included in the complex of treatment measures performed with peripheral nerve injuries at any rear hospital. Electrogymnastics with pulse currents and active electrogymnastics were performed in specialized neurosurgical hospitals and sections.

The complex of measures in treating firearms injuries to the peripheral nerves during the Great Patriotic War also included work therapy, which gave a certain effect in the sense of restoring the function of individual afflicted muscle groups. The purpose of work therapy is the inclusion of an isolated movement or an entire movement act into some sort of purposeful locomotory process.

In cases of total paralysis, restorative measures of the neurosurgical type are first required, and then exercise and work therapy may be applied.

The development of compensatory mechanisms in work /346
therapy, according to the data of V. N. Leont'yev and A. V. Zaporozhets, proceeds gradually. First there is general compensation of the entire extremity, then the following period of compensation ensues, in which the greatest part of the load falls on the healthy muscles, and only after this does the development of vicarious compensation begin, when the increased

volume of movement of the afflicted musculature makes it possible to greater part of the load to the paretic musculature.

The basic principle in the application of work therapy was the fact that the direction of movements of the injured extremity worked out a series of locomotory habits which took on an automatic character, and the patient was thereby able to consciously develop the detailed functions of the injured organ.

Work therapy, as all the other parts of complex treatment of injuries to the peripheral nerves, was organized in regard to acceptability and was dosed at all stages of treatment.

Peripheral nerve injuries were very often combined with injuries to the vessels, which naturally caused a number of changes in the clinical picture. The application of a tourniquet for a lengthy period immediately after the wound was sustained, ligation of the vessels during operative intervention, and the circulatory disorders of an ischemic character arising in connection with this were the reason for ischemic contractures and pains, sometimes with elements of causalgia. In these cases, a physical agent was used which had vascular enlargement properties and which had a definite effect on vascular innervation.

From the times of the first studies conducted with high frequency currents, it was known that they possess vascular enlargement properties. A series of experimental and clinical works have proven that the ultra-high frequency electrical field causes a short-term phase of vascular contraction, followed by acute enlargement and a subsequent retardation of the current in the blood. This is why in cases of ischemic contractures and pains the application of an ultra-high frequency electrical field is substantiated along with paraffin therapy or mud therapy.

The methodology of UHF therapy was as follows: oligothermal dosing with placement of the distal section of the extremity between the electrodes (condenser field), distance between the electrodes and the extremity on both sides -- 5 cm; 18-20 procedures, each lasting 5-10 minutes.

UHF therapy was performed every other day, alternating with either paraffin therapy or mud therapy. Their methodology was as follows: paraffin was applied to the entire extremity, temperature of application was 60-65°, 20-25 procedures, each lasting 45 minutes. Mud therapy was performed according to the following methodology: the mud was applied to the entire extremity; the temperature of the mud was 40-45°; there were a total of 20-25 treatments, each lasting 20-25 minutes.

In firearms injuries to the peripheral nerves, aside from the changes in the zone of innervation of branches below the point of injury, in some cases there were observed locomotory, sensitivity and vegetative disorders in areas located in the zone of other undamaged nerve branches or other nerves of the afflicted extremity.

We are speaking here of reflex syndromes, primary among which are reflex paralyses, reflex contractures and reflex vegetative-trophic disorders. With conservative treatment of the patients with these syndromes, they stemmed from the pathogenesis of the latter. Despite the variation in reflex syndromes, they have a number of general characteristics and may be given a singular explanation.

The only reason for the emergence of these syndromes /347 is the focus at the periphery. The stimuli which come from here and go to the nodes of the boundary trunk cause excitation in them and at the same time inhibition of locomotory and sensory animal apparata, as well as vegetative and trophic

disorders. As a result the patients developed reflex paralysis, amiotrophy, hypotonia, hypertrichosis, hyperhydrosis, ulcers, etc. On the other hand, the center of irritation at the periphery may cause exclusion or inhibition of the vegetative apparata and inhibition of the locomotory systems. In such cases, another clinical picture was noted -- hyperreflexia, contractures. hyperkinesia and pain syndrome. All this indicates the necessity of acting first of all on the center of the irritation.

Cicatrical connective tissue elements, neuromas, normal nerve fibers, and altered vascular network are noted in the injured section of the nerve. Cicatrical growth have a particular significance in these cases. In his studies, P. K. Anokhin showed that the scar has the capacity to generalize the impulses which come into it, as a result of which a number of disorders arise. Neuromas take on an increased sensitivity to various mechanical and other stimuli. Prolonged irritation of the sensory fibers of the afflicted section, neuroma or scar is directed toward the center and creates focal areas of inhibition and excitation.

According to the biological action of physical agents, the application of ion-galvanization with potassium iodide, paraffin therapy or mud therapy are indicated for the purpose of affecting the peripheral focus of the irritation.

Ion galvanization with potassium iodide is performed as follows: the electrodes are placed at the point of the trauma and at the section opposite it (transverse methodology).

The current voltage is 0.1-0.2 mA per 1 $cm^2$ of electrode area, and there are 25-30 treatments, each lasting 25-30 minutes. The treatments are performed daily.

Before the iodine ion galvanization, paraffin therapy was performed according to the following methodology: the paraffin was applied to the entire extremity, application temperature was 55-60°, and the duration of the procedure was 40-45 minutes. The procedures were performed daily. Mud therapy was performed in cases when for technical reasons it was impossible to use paraffin therapy.

The methodology of mud therapy is as follows: application to the entire injured extremity, temperature of the mud is 40-45°, with 25-30 treatments, each lasting 20-25 minutes. In those cases when the use of mud caused intensification of pains, mud of a lower temperature (30-35°) was used.

Immediately after the paraffin therapy and the mud treatment, the patient was directed for iodine ion galvanization. In these cases, daily exercise therapy was indicated with consideration of the basic principle conditions presented above in describing the methodology of exercise therapy. Exercise therapy was performed daily before application of the ion galvanization and paraffin therapy. However, in a significant number of cases either the source of the irritation was unclear, or the therapy which we recommended did not give the desired effect, which could most likely be explained by an over-excitation of the nervous system, which did not disappear even after elimination of the center of peripheral irritation.

In these cases, the severance of the reflex arch for pathological reflexes could be effective in a therapeutic sense, which, according to the proposal of A. M. Grinshteyn, was accomplished by the operation of preganglionar sympathectomy.

In these cases, ultraviolet erythemotherapy was used /348 before the operative intervention for the same purpose of breaking the reflex arch of the pathological reflexes. It was performed according to the following methodology: ultraviolet erythema (4-5 biodoses) in 2-3 treatments per area to the corresponding nodes of the boundary sympathetic trunk; to the fourth-seventh thoracic -- in injuries of the upper extremities, and to the tenth thoracic and second lumbar -- in injuries to the lower extremities.

As a result of numerous observations performed during the period of the Great Patriotic War, the favorable effect of treating reflex syndromes with a UHF electrical field was noted. The methodology of the UHF therapy in these cases was combined: extra-focal and focal. In the initial period of treatment, the extra-focal methodology was used: a UHF collar or a UHF belt, depending on the localization of the reflex syndrome on the upper or lower extremities. The collar electrode was located at the level of the VII cervical and the upper thoracic vertebrae, i.e., the localization of the electrode corresponded to the cutaneous segments from the fourth cervical to the second thoracic. The second electrode was removed. The UHF belt was located at the level of the lower thoracic and lumbar vertebrae. The action was single electrode (the second electrode was removed). The dosage was oligothermal, with the treatments repeated daily and each treatment lasting 5-7-10 minutes.

After 6-10 treatments of extra-focal action, action on the focal point was begun; a capacitor field with electrodes placed at opposite surfaces of the body area subject to the effect. The air gap is 5-7 cm, the procedure lasts for 5-7-10 minutes with oligothermal dosage.

The UHF therapy was conducted daily, with alternation of focal and extra-focal procedures. Fifteen to twenty treatments were performed according to each methodology.

The favorable therapeutic effect of the UHF field in reflex syndromes may be explained by the changes in ion and electro-ion conjuncture, changes in biocolloids and particular sensitivity to high frequency oscillations of elements of the vegetative nervous system which occur under the influence of UHF.

In injuries to the peripheral nerves, as well as in combined nerve and bone injuries with sharply expressed inflammatory manifestations, the application of such a physical agent is indicated which would have a favorable effect on the course of the inflammatory process.

As we know, the UHF field has a high therapeutic effectiveness in the battle against inflammatory and purulent processes. This is why in these cases before the above-described methodology of complex balneo-physiotherapy was performed, action of a UHF field was employed in the following way: the extremity -- area of injury -- was located between the electrodes (gap, i.e., the distance from each electrode to the extremity was 5 cm), dosage was oligothermal, 6-8 procedures were performed, each lasting for 6-8-10 minutes; the sessions were performed daily. In the significant majority of cases, after 3-5 days of this course of UHF therapy the inflammatory manifestations had almost completely disappeared and conditions were created which allowed the application of physiotherapy and exercise therapy according to the methodology described above.

As we know, one of the symptoms which was often observed in nerve injuries is the appearance of ulcerations which do not heal for long periods. The mechanism of the appearance of trophic ulcers in these cases is to a significant degree /349

explained by the following: as a result of the emergence of irritation of center-directed paths at the periphery, the work of the vegetative centers of the cortex of the brain, spinal cord, medulla oblongata and diencephalon is distorted. The vasomotor, secretory and trophic impulses emanating from here create abnormal conditions of blood filling at the periphery, abnormal secretion of glands, alter the tonus of the musculature and the basic metabolism in such a way that the necrosis of cells and tissues ensues from the most insignificant reasons.

The methodology of treating trophic ulcers with galvanic current is as follows: the cathode is applied to the proximal section of the extremity, the anode -- to the distal section, i.e., on the trophic ulcer (the lining under the anode must be boiled each time before the procedure). The procedures are performed every other day, with a total of 25-30 procedures, each lasting 30 minutes. Further numerous clinical observations during the period of the Great Patriotic War confirmed the significant effectiveness of longitudinal galvanization of trophic ulcers with peripheral nerve injuries.

If galvanization alone was not successful in achieving full healing of the ulcers, local darsonvalization was performed after the course of galvanization in the area of the ulcer (the procedures were performed daily, with a total of 12-15 procedures each lasting 8-10 minutes).

The effectiveness of longitudinal galvanization and local darsonvalization in treating trophic ulcers was increased by the application of local light bath. The definite effectiveness of treating trophic ulcers with galvanic current is explained primarily by the change in the ion concentration in the injured areas. As a result there was an effect also on the vegetative system in the sense of bringing the process of stimulation in the given nerve closer to normal, i.e., to the normotrophic action of the process of nerve stimulation.

The question of the therapy of causalgic syndroms is a rather acute one. The study of the functional condition of the nervous system in causalgia by determination of electrocutaneous potentials, excitability and lability at the point of stimulus action and pain localization, as well as the application of the method of anelectrotonic removal and catelectrotonic deepening of the anatomical process has shown that in causalgia there is a neurodynamic process which bears a clearly expressed parabiotic character (D. A. Lapitskiy). This was the basis for action by an electric current for purposes of stopping or reducing burning pains in causalgia (the anode was applied at the point of pain projection, the cathode -- at the proximal section of the extremity). The current voltage was 0.1-0.2 mA per 1 $cm^2$ of electrode area, there were a total of 25-30 procedures, each lasting 25-30 minutes. The procedures were performed daily.

Several phases are distinguished in the course of causalgic syndrome: each time segment which passes from the moment the wound is sustained is characterized by its own morpho-physiological mechanisms and level of localization.

At the first stage, several days (10-14) after the injury, the peripheral receptors play the primary role. The injury creates a focus of irritation, which sends out a constant flow of pain impulses. Used in this period, aside from the longitudinal galvanization - an electrocurrent, was also ion galvanization with novocaine for purposes of acting on the injured nerve trunk and peripheral cutaneous receptors by means of galvanic current and novocaine ions. The methodology of ion galvanization was as follows: the anode with novocaine was applied to the point of pain projection, the cathode -- to /350 the proximal section of the extremity. The current voltage was 0.1-0.2 mA per 1 $cm^2$ of electrode area. There were a total of 25-30 procedures, each lasting 25-30 minutes. The procedures were performed daily.

If the pain syndrome of causalgic character was accompanied by vascular shifts based on ishemia, then paraffin therapy and ultra-high frequency electrical field were used.

The UHF field was used in the form of a capacitor field with gaps between the electrodes and the distal section of the extremity (the point of pain projection) of 5 cm on each side. Dosage was oligothermal, with a total of 15-20 procedures, each lasting 8-10 minutes. The procedures were performed every other day.

Paraffin therapy was performed every other day on the days when the UHF therapy was not being done. Applications were to the distal section of the extremity, with a temperature of 38-40°. There was a total of 15-20 procedures, each lasting 15-20 minutes.

If the reason for the causalgia was scars surrounding and pressing on the nerve, therapeutic effect was obtained from alternating transverse ionization with potassium iodide and mud therapy.

Ionization with potassium iodide was performed as follows: one electrode -- the cathode -- was applied to the place of injury, the other -- to the opposite section of the extremity above and below the point of injury. The current voltage was 0.1-0.2 mA per 1 $cm^2$ of electrode area. There was a total of 25-30 procedures, each lasting 25-30 minutes.

Mud was used in the form of applications to the area of pain and to the entire extremity in the area of the injured nerve. The temperature of the mud was 38°. The procedures were performed every other day, alternating with ionization with potassium iodide. The procedure lasted for 15-20 minutes.

The positive effect of mud therapy may be explained by the resolving action of the mud on the local inflammatory process in the sympathetic fibers, which leads to a reduction in irritation at the periphery and at the same time to a freeing (by reflex) of a certain portion of the overstimulation of central pain receptors in the area of the visual tuber.

The absence of effect from the described therapy which occurred in a number of cases was evidently explained by the fact that the next level -- the spinal-trunk section -- had already become involved in the development of the pathological process. In this period, an effective therapeutic measure, as in cases of reflex contractures and paralyses, was the severance of the reflex arch of the pathological reflexes, which was achieved by using ultraviolet erythemotherapy according to the same methodology as in cases of reflex contractures: action by erythemic doses of ultraviolet rays on the area of the boundary trunk -- the fourth-seventh thoracic segment in injuries to the upper extremities, and to the tenth thoracic and second lumbar in injuries to the lower extremities.

Used simultaneously with physiotherapy were a number of pain killing and anti-inflammatory medicinal substances (pyramidon, bromides, sulfamide preparations, vitamins $B_1$ and C).

According to the observations of B. V. Likhterman, with pain syndromes in the acute period, UHF therapy should be started with the application of extra-focal action in the form of a UHF collar or UHF belt, depending on the localization of the injuries and the degree of involvement of the spinal and cerebral centers into the process. This methodology, in the opinion of the author, is better than the focal in facilitating an increase in the regulatory function of the vegetative nervous system and has a favorable effect on inflammatory,

vegetative-vasomotor disruptions and pain phenomena in the /351
in the area of the injured extremity.

To obtain maximal therapeutic effect, extra-focal action was combined with direct action of UHF in the area of the injured extremity, which was begun 6-10 hours after the extra-focal segmental procedures. Here, B. V. Likhterman used the single electrode action of UHF in the area of both hands with injury to one of the upper extremities, or in the areas of both feet with injury to one of the lower extremities. The procedures were performed daily, alternating focal and extra-focal action. The dosage was oligothermal, and the session lasted for 5-7-10 minutes. There were 10-15 sessions according to each methodology. The described sequence of applying focal and extra-focal UHF therapy is a scheme, divergence from which was dictated by the specifics of the individual case and by the reaction of the patient.

If large metallic fragments were found in the tissues, or small ones located near the nerve trunk or a major vessel, extra-focal UHF action was used in all syndromes of injury to the peripheral nerves.

As we have previously mentioned, even in those cases when surgical intervention was assumed, in the overwhelming majority of cases approximately 2 months passed from the moment the wound was sustained to the operation. This time was fully sufficient to perform a course of complex conservative therapy even in cases when operative intervention was indicated. Close observation with systematic treatment during this period (2-3 months) finalized the decision as to the necessity of operative intervention and its time.

Thus, in all cases of peripheral nerve injuries, treatment after surgical processing was begun with the application of physiotherapy, exercise therapy, and medicines. Sub-

sequently, a detailed analysis of the data from clinical study and the course of each individual case makes it possible to answer the question of expediency of surgical intervention.

It must be noted that in a considerable number of cases where operative treatment had been indicated on the basis of study methods available to clinical practitioners, the application of conservative treatment according to the methodology described above before the operation gave such an effect that the question of operation was no longer applicable.

In those cases when conservative treatment did not give the necessary effect, operative intervention after the first course of conservative therapy demonstrated the expediency of performing physiotherapy and exercise therapy in the first days after the injury and before the operation. As a result of this (pre-operative) course of treatment, pre-conditions were created for a more successful surgical intervention. This was achieved by means of clarifying hidden (latent) infection, which took place as a result of using exercise therapy and massage, as well as by acting on the pathological processes in the nerve trunk itself and on the mechanical factors conditioning its compression. In these cases, as a result of the treatment performed prior to the operation, it was possible to achieve a better (as compared with cases when treatment had not been performed before the operation) condition of the afflicted tissues, and to avoid extensive involvement of the nerve into the scar and the inflammatory process.

The application of physical agents and exercise therapy in the very first days after injury also had a favoral effect in cases of nerve injuries combined with bone fractures and /352 osteomyelitis in terms of bone consolidation and the course of the osteomyelitic process.

The facts presented above are a sufficient basis for the widespread application of physiotherapy and exercise therapy before the operation also in cases of firearms nerve injuries where operative intervention is indicated.

## The conservative method as a part of complex treatment: operation and conservative treatment

Operative treatment -- neurolysis, neuroma excision, nerve suture application and plasty measures -- although they do create conditions for regeneration, they are still not sufficient for normal, moreover for rapid restoration of the nerve function.

Suture application itself (silk thread) may cause reactive phenomena consisting of the growth of connective tissue. It is also necessary to consider the possibility of secondary (post-operative) scar formation. The injury of large, and particularly small, vessels played a rather significant role in the pathogenesis of peripheral nerve injuries as well as in their regeneration.

As we know, venous blood circulation is rather extensive in the epi-, peri- and endoneurium. The disruption of venous blood circulation leads to severe disruptions in the function of the peripheral nerves even without disruption of their integrity. These disruptions in turn condition further disorders in blood circulation in the tissues surrounding the nerve, thereby creating conditions for the development of the dystrophic process. This is why vascular phenomena play such an important role in the pathogenesis of these injuries.

Operative intervention alone is not enough to facilitate the most rapid growth of nerve fibers and the restoration of the nerve function.

The facts presented are the basis for performing balneo-physiotherapy and exercise therapy, which would facilitate increased regenerative processes of the nerve trunk, in all cases of operative intervention.

In order to solve the problem of the most expedient time after the operation for beginning the complex of balneo-physiotherapy and exercise therapy in the sense of therapeutic effectiveness, O. M. Vil'chur compared the length of hospital stay and the results of treatment in two groups of patients with peripheral nerve injuries. The first group included cases when balneo-physiotherapy and exercise therapy were performed after a considerable period of time (from 1½ to 3 months) after the operative intervention. The second group included those cases in which exercise therapy and physio-therapy were performed immediately after the operation.

It was possible to establish that balneo-physiotherapy and exercise therapy performed according to the complexes described above immediately after operative intervention increased the functional restoration of the injured extremities by 10.0 - 20.0% as compared with those cases where the balneo-physiotherapy was performed 1½-3 months after the operative intervention.

In the first (5-7) days after the nerve suture operation, longitudinal galvanization was performed according to the methodology described above and exercise therapy was performed in accordance with the basic principles of application of differentiated exercise therapy.

In 15-20 days after nerve suture application and in the very first days after the neurolysis operation, transverse ionization with potassium iodide, which was alternated with longitudinal galvanization, was prescribed. /353

In those cases when the neurolysis operation was performed for purposes of combatting the causalgic syndrome, the therapeutic effect of this operation was more greatly expressed if transverse ionization with potassium iodide was performed immediately after the operation. As we know, the neurolysis operation in the presence of causalgic syndrome sometimes gives a therapeutic effect, but it is usually short lived. In these cases, the application of transverse ionization with potassium iodide in the very first days after the operation often completely rid the patients of their pains.

In surgical treatment of causalgia calculated to effect the sympathetic nervuus system (paravertebral novocaine block, periarterial sympathectomy, gangliectomy), a "residual pain symptomatology" was retained in a significant part of the patients. In these cases, as well as in cases where operative intervention yielded an insignificant therapeutic effect, ultraviolet erythmotherapy was used. The methodology in these cases was as follows: with pains in the upper extremities, irradiation (in sections) was performed first on the area of the back at level $D_4$ - $D_7$, then the shoulder girdle and the upper extremity on the healthy side.

In cases of absence or insignificant effect, irradiation of the afflicted side was performed in the same sequence. The dosage was erythemic, 4-5 biodoses, irradiation in sections was performed daily: every day -- another section. Each section was irradiated 3-4 times.

With pains in the lower extremity, irradiation was performed in the area of the back at the level of the X thoracic and the II lumbar vertebra, then the pelvic girdle and the lower extremity on the healthy side. If there was no effect, the irradiation was performed in the same sequence on the afflicted side.

After an operation with the use of a transplant, resolving (mud therapy, paraffin therapy, ionization with potassium iodide) was counterindicated. In these cases, extra-focal ultraviolet radiation was used in small doses to restore the disrupted trophic, circulatory and metabolic mechanisms. However, considering the pathologo-anatomical data and the dynamics of clinical symptoms observed in part of the cases of transplant application, no significant effect was observed from the application of ultraviolet therapy.

Based on the biological action of galvanic current, particularly its influence on the course of trophic ulcers with nerve injury, and based also on the effects of the early application of longitudinal galvanization after nerve suture application in terms of accelerating regenerative processes, the performance of a course of longitudinal galvanization 1-1½ months after an operation with the use of a transplant turned out to be expedient. The number of observations performed in just cases is small. However, the positive results obtained in all cases (healing of trophic ulcers, acceleration of nerve function restoration), as well as the absence of any negative data, confirm the expediency of longitudinal galvanization in patients who have undergone transplant operations.

Exercise therapy was performed in all cases of using transplants, as it was in general with all treatment measures implemented due to peripheral nerve injuries.

Table 28. Time for restoration of movement with conservative treatment by individual nerves (in percentages)

| a - Название нерва / b - Срок наблюдения | c - До 1 месяца | d - До 2 месяцев | e - До 3 месяцев | f - До 4 месяцев | g - До 5 месяцев | h - До 6 месяцев |
|---|---|---|---|---|---|---|
| n - Лучевой | — | 11,5 | 19,2 | — | 3,8 | 11,6 |
| o - Срединный | — | 17,3 | 13,8 | 10,3 | — | 17,2 |
| p - Локтевой | — | — | — | 50,0 | — | — |
| q - Локтевой и срединный | — | — | 8,4 | 8,3 | 8,3 | 8,3 |
| r - Лучевой и срединный | — | — | 4,8 | 9,5 | 4,8 | — |
| s - Лучевой и локтевой | — | — | — | — | 16,7 | 50,0 |
| t - Локтевой, лучевой и срединный | — | — | 5,8 | — | — | 11,8 |
| u - Седалищный | — | 4,9 | 4,9 | 2,4 | 7,3 | 17,1 |
| v - Малоберцовый | — | 2,7 | 2,6 | 2,6 | 23,7 | 7,9 |
| w - Большеберцовый | — | 10,0 | 10,0 | 20,0 | 20,0 | — |
| x - Берцовые | — | 3,2 | 6,5 | 3,2 | 6,5 | 9,6 |
| y - Седалищный и бедренный | — | — | — | — | — | — |
| m - Итого | — | 4,2 | 7,5 | 5,7 | 6,9 | 13,5 |

| a - Название нерва / b - Срок наблюдения | i - До 8 месяцев | j - До 1 года | k - До 2 лет | l - До 3 лет | m - Итого |
|---|---|---|---|---|---|
| n - Лучевой | 7,7 | 26,9 | 7,7 | 11,6 | 100,0 |
| o - Срединный | 3,5 | 13,8 | 13,8 | 10,3 | 100,0 |
| p - Локтевой | — | — | 50,0 | — | 100,0 |
| q - Локтевой и срединный | 12,5 | 25,0 | 16,7 | 12,5 | 100,0 |
| r - Лучевой и срединный | 4,8 | 14,3 | 38,0 | 23,8 | 100,0 |
| s - Лучевой и локтевой | — | — | 16,6 | 16,7 | 100,0 |
| t - Локтевой, лучевой и срединный | 5,9 | 23,5 | 47,1 | 5,9 | 100,0 |
| u - Седалищный | 4,9 | 19,5 | 24,4 | 14,6 | 100,0 |
| v - Малоберцовый | — | 23,7 | 18,4 | 18,4 | 100,0 |
| w - Большеберцовый | — | 20,0 | 20,0 | — | 100,0 |
| x - Берцовые | 6,5 | 29,0 | 22,6 | 12,9 | 100,0 |
| y - Седалищный и бедренный | — | — | 33,3 | 66,7 | 100,0 |
| m - Итого | 5,7 | 24,0 | 20,2 | 12,3 | 100,0 |

Key: a - Name of nerve; b - Times of observation; c - Up to 1 month; d - Up to 2 months; e - Up to 3 months; f - Up to 4 months; g - Up to 5 months; h - Up to 6 months; i - Up to 8 months; j - Up to 1 year; k - Up to 2 years; l - Up to 3 years; m - Total; n - Radial; o - Median; p - Ulnar; q - Ulnar and median; r - Radial and median; s - Radial and ulnar; t - Ulnar, radial and median; u - Sciatic; v - Fibular; w - Tibial; x - Leg nerves; y - Sciatic and femoral.

Table 29. Time for restoration of sensitivity with conservative treatment by individual nerves (in percentages)

| a - Название нерва / b - Срок наблюдения | c - До 1 месяца | d - До 2 месяцев | e - До 3 месяцев | f - До 4 месяцев | g - До 5 месяцев | h - До 6 месяцев |
|---|---|---|---|---|---|---|
| n - Лучевой | — | — | 14,3 | — | — | — |
| o - Срединный | — | — | 20,0 | — | — | — |
| p - Локтевой | — | — | 44,4 | 22,2 | — | 11,1 |
| q - Локтевой и срединный | — | — | — | — | 14,3 | 14,3 |
| r - Лучевой и срединный | — | — | — | — | 16,7 | 16,6 |
| s - Локтевой и лучевой | — | — | — | — | — | — |
| t - Лучевой, локтевой и срединный | — | — | — | — | — | — |
| u - Седалищный | — | — | — | — | 9,1 | 9,1 |
| v - Малоберцовый | — | — | — | — | — | 33,3 |
| w - Большеберцовый | — | — | — | — | — | 50,0 |
| x Берцовые | — | — | — | — | — | — |
| m - Итого | — | — | 11,0 | 4,9 | 2,4 | 8,5 |

| a - Название нерва / b - Срок наблюдения | i - До 8 месяцев | j - До 1 года | k - До 2 лет | l - До 3 лет | m - Итого |
|---|---|---|---|---|---|
| n - Лучевой | 14,3 | 50,0 | 14,3 | 7,1 | 100,0 |
| o - Срединный | 20,0 | 40,0 | 20,0 | — | 100,0 |
| p - Локтевой | 11,1 | 11,2 | — | — | 100,0 |
| q - Локтевой и срединный | 14,3 | 14,3 | 14,3 | 28,5 | 100,0 |
| r - Лучевой и срединный | 16,7 | 33,3 | — | 16,7 | 100,0 |
| s - Локтевой и лучевой | 50,0 | — | 50,0 | — | 100,0 |
| t - Лучевой, локтевой и срединный | 25,0 | — | 25,0 | 50,0 | 100,0 |
| u - Седалищный | 27,3 | 9,1 | 36,4 | 9,0 | 100,0 |
| v - Малоберцовый | 16,7 | — | 33,3 | 16,7 | 100,0 |
| w - Большеберцовый | 50,0 | — | — | — | 100,0 |
| x Берцовые | — | — | 40,0 | 60,0 | 100,0 |
| m - Итого | 9,8 | 24,7 | 27,7 | 11,0 | 100,0 |

Key: a - Name of nerve; b - Time of observation; c - Up to 1 month; d - Up to 2 months; e - Up to 3 months; f - Up to 4 months; g - Up to 5 months; h - Up to 6 months; i - Up to 8 months; j - Up to 1 year; k - Up to 2 years; l - Up to 3 years; m - Total; n - Radial; o - Median; p - Ulnar; q - Ulnar and median; r - Radial and median; s - Ulnar and radial; t - Radial, ulnar and median; u - Sciatic; v - Fibular; w - Tibial; x - Leg nerves.

Immediate outcomes and long term results with conservative therapy

A definite therapeutic effect was noted as a result of complex conservative treatment. The degree of this effect varied depending on a number of factors: the character of the injury, the combined injury of the nerve with that of the bones and vessels, the level of injury, the time when conservative therapy was begun, and the complex of therapeutic measures.

To evaluate the degree of therapeutic effect, materials from the development of illness histories were used, which made it possible to judge the immediate results of conservative therapy during the patient's stay at the hospital. However, in order to judge the true effect of any therapeutic measure, it is necessary to consider the long term results of the treatment. For this purpose, special questionnaires were developed to be sent out to the patients, and part of the patients were again examined under hospital as well as polyclinic conditions, which altogether comprised over 2,000 observations.

All the patients with peripheral nerve injuries were prescribed physiotherapy according to a certain complex at various periods. The overwhelming majority (82.7%) received mixed treatment which included splinting, various physiotherapy complexes, balneotherapy, exercise therapy, work therapy, and massage. An insignificant number of patients (0.4%) were given novocaine block of the nerve trunks with physiotherapy, block of the sympathetic nodes with physiotherapy -- 0.2%. Exercise therapy along was used in 7.1% of the cases, physiotherapy alone -- in 2.5%, balneotherapy alone -- in 0.4%, only massage -- in 0.2%, and only splinting -- in 0.8%.

Immediately after the conservative treatment performed at the hospital, a certain percentage of the cases showed

favorable shifts on the part of the locomotory and sensory function. Restoration usually started with a "hint" of a certain movement or with a rapidly exhausting movement, which could be found only in such a ("lightened") position of the extremity when minimal force is required to determine the effect of muscle contraction and when the weight of the extremity itself is excluded. In these cases it was considered which movements were associated with the regenerative process in the nerve and which were conditioned by the replacement function of the neighboring nerves and muscles. According to the materials for the development of illness histories, it was possible to clarify the times for restoration of movement in injuries to individual nerves after the application of conservative therapy (table 28).

As we see from table 28, under the influence of conservative therapy, the restoration of movement after firearms injuries to the nerves of the upper extremity began with the second months. This was most often observed in injury to the median nerve (17.3%), then to the radial (11.5%), significantly later -- in the third and fourth months -- movement was restored with injury to the ulnar nerve, as well as in combined injuries to the nerves of the upper extremity.

The restoration of movement in injury to the nerve trunks of the lower extremity also occurred in the second month, but was noted in a significantly lesser number of cases (tibial nerve -- 10.0%, sciatic nerve -- 4.9%, nerves of the leg -- 3.2%) than in injuries to the nerves of the upper extremities. From this same table we see that the locomotory function was most often (29.7%) restored in periods of from 6 months to 1 year, and only in 11.7% of the cases /356 in a period of up to 3 months from the moment of injury.

It is also necessary to stress the fact that in a significant number of patients (32.5%) the restoration of movement occurred in a period of from 1 year to 3 years after the injury (fig. 137).

The movements which appear under the influence of conservative treatment are different with injuries to various nerves and depend on the degree of conductivity disruption in the nerve trunk caused by its injury. Thus, in injury to the radial nerve, a slower falling of the hand was noted, as well as a reduction in the inclination toward acute pronation. Subsequently there is a "hint" of active (in a relaxed position) extension of the hand, but the capacity for active extension of the fingers had already appeared. The last to be restored is the extension of the index finger and thumb.

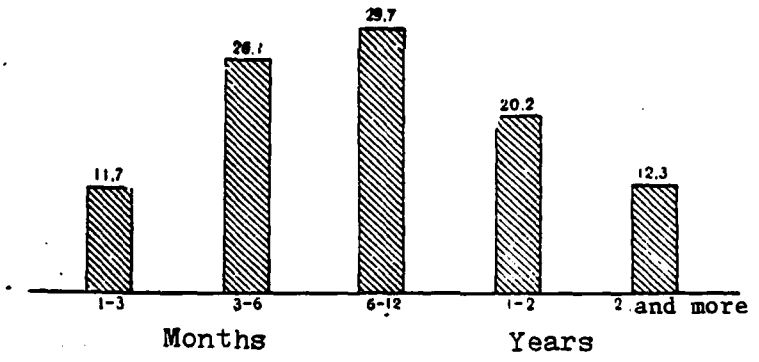



Fig. 137. Times of restoration of locomotory disruptions after conservative treatment of firearms injuries to the peripheral nerves.

With injury to the median nerve, the first to be noted was the restoration of pronation, then -- flexion of the index finger, and last -- opposition of the thumb.

The restoration of conductivity of the ulnar nerve proceeds more slowly than that of the median and radial, particularly in those cases where the nerve injury occurred at the forearm. The first to appear is movement in the flexors of the hand, and then the fingers. The movement of small muscles of the hand is the last to be restored. Here it is necessary to keep in mind the fact that differentiated movements of the fingers may be performed not only due to the small muscles of the hand, but also by the replacement functions of the other muscles.

With combined injuries to several nerves of the upper extremity, as well as of the neurovascular fascicle, the reverse development of motor losses proceeds much more slowly, but in the same sequence as with injury to the individual nerves. The same may be noted in cases of injury to the brachial plexus: the restoration of the motor function takes place primarily in the proximal regions.

With severe injuries to the sciatic nerve and its branches, the locomotory function is the first to be restored, starting with the proximal regions of the extremity. The last to be restored is the long digital flexor and the small muscles of the foot.

The locomotory function, as well as other functions, are restored most slowly in patients who had undergone vascular ligation immediately after the injury was sustained.

From an analysis of the development of materials of /357 illness history we have been able to establish the relative frequency of times for restoration of sensitivity after the performed conservative therapy (table 29).

As we see from table 29, the restoration of superficial sensitivity began in the upper extremity with the third month and most often occurred after injury to the ulnar nerve (44.4%), then the median (20.0%), and least often (14.3%) -- after injury to the radial nerve.

With combined injuries to the nerve trunks of the upper extremity, the restoration of sensitivity occurred later (in 5 months) than with isolated injury to the nerve.

With injury to the lower extremities, the restoration of sensitivity began in the fifth or sixth month and was observed most often with injuries to the fibular and tibial nerve (50.0 and 33.3%), and significantly less often (9.1%) -- with injury to the sciatic nerve.

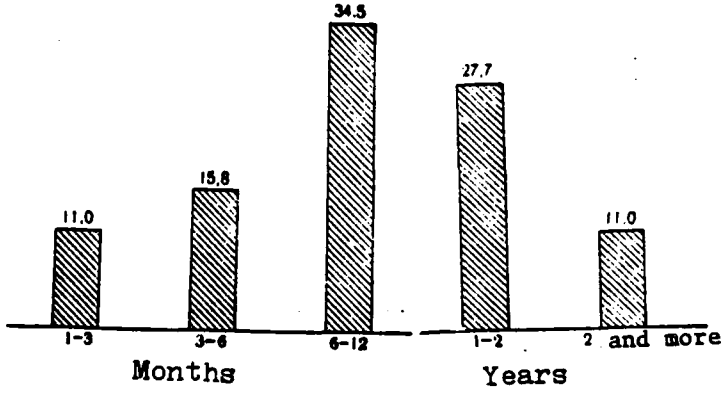



Fig. 138. Times for the restoration of sensitivity disruptions after conservative treatment of firearms injuries to the peripheral nerves.

The highest percentage (34.5) of restoration of sensitivity was noted in the period of from 6 months to 1 year. In 27.7% of the cases, restoration of sensitivity occurred before 2 years, and in 11.0% -- before 3 years from the moment of injury (fig. 138).

According to the materials for the development of illness histories, the percentage of restoration of locomotory function in a period of up to 6 months is equal to 37.8%, while the percent of restoration of sensitivity in this same period is equal to 26.8%.

These facts show that the locomotory function is restored sooner than sensitivity. Even with full restoration of the locomotory function, sensitivity disruptions (sometimes of a hyperpathic character) may still continue for a long time. The same may be noted also in respect to vascular and trophic disruptions.

The reflexes in the overwhelming majority of severe firearms injuries to the nerves are the last to be restored.

A great effect on the outcome of conservative treatment is given by the duration of the treatment (table 30).

As we see from table 30, the overwhelming majority of the wounded patients (78.0%) underwent conservative treatment for a period of 3-6 months, 1.5% -- up to 1 month, 8.2% -- up to 2 months, 8.8% -- up to 8 months, 3.3% -- up to 1 year, and 0.2% -- up to 2 years.

As concerns the treatment of peripheral nerve injuries, /359 as we see from this table, in most cases it lasted for 3-4 months.

Table 30 /358

The duration of conservative treatment according to the individual nerves (in percentages)

| a - Название нерва / b - Срок наблюдения | c - До 1 месяца | d - До 2 месяцев | e - До 3 месяцев | f - До 4 месяцев | g - До 5 месяцев | h - До 6 месяцев | i - До 8 месяцев | j - До 1 года | k - До 2 лет | l - До 3 лет | m - Итого |
|---|---|---|---|---|---|---|---|---|---|---|---|
| n - Плечевое сплетение | 1,4 | 7,9 | 27,6 | 29,6 | 15,8 | 9,7 | 6,2 | 1,8 | — | — | 100,0 |
| o - Лучевой | 2,5 | 10,4 | 23,5 | 26,8 | 17,4 | 10,4 | 7,5 | 1,4 | — | 0,1 | 100,0 |
| p - Срединный | 2,5 | 11,2 | 26,0 | 26,2 | 17,2 | 10,2 | 5,5 | 1,0 | 0,1 | 0,1 | 100,0 |
| q - Локтевой | 3,3 | 15,0 | 25,7 | 25,5 | 15,2 | 9,0 | 4,7 | 1,4 | 0,2 | — | 100,0 |
| r - Локтевой и срединный | 0,6 | 9,0 | 23,7 | 30,6 | 18,3 | 8,0 | 6,6 | 3,2 | — | — | 100,0 |
| s - Лучевой и срединный | 1,8 | 9,3 | 21,9 | 30,2 | 17,9 | 9,7 | 6,0 | 2,8 | 0,4 | — | 100,0 |
| t - Лучевой и локтевой | 0,1 | 7,9 | 19,7 | 32,6 | 19,5 | 12,3 | 6,2 | 1,7 | — | — | 100,0 |
| u - Лучевой, локтевой и срединный | — | 7,2 | 23,8 | 29,8 | 17,8 | 9,3 | 9,4 | 2,3 | 0,2 | 0,2 | 100,0 |
| v - Седалищный | 0,8 | 4,0 | 17,4 | 23,8 | 22,4 | 14,1 | 12,1 | 5,2 | 0,2 | — | 100,0 |
| w - Малоберцовый | 0,7 | 5,1 | 18,0 | 20,9 | 22,0 | 15,2 | 11,5 | 6,5 | 0,1 | — | 100,0 |
| x - Большеберцовый | 0,5 | 6,2 | 19,2 | 22,8 | 17,6 | 14,5 | 13,5 | 5,7 | — | — | 100,0 |
| y - Берцовые | 0,4 | 5,5 | 16,3 | 21,1 | 22,5 | 15,3 | 13,0 | 5,2 | 0,7 | — | 100,0 |
| m - Итого | 1,5 | 8,2 | 21,7 | 25,6 | 19,0 | 11,7 | 8,8 | 3,3 | 0,2 | — | 100,0 |

a - Name of nerve; b - Time of observation; c - Up to 1 month; d - Up to 2 months; e - Up to 3 months; f - Up to 4 months; g - Up to 5 months; h - Up to 6 months; i - Up to 8 months; j - Up to 1 year; k - Up to 2 years; l - Up to 3 years; m - Total; n - Brachial plexus; o - Radial; p - Median; q - Ulnar; r - Ulnar and median; s - Radial and median; t - Radial and ulnar; u - Radial, ulnar and median; v - Sciatic; w - Fibular; x - Tibial; y - Nerves of the leg.

Table 31

Results of conservative treatment in hospitals depending on the character of injury to the extremity (in percentages)

| Result of treatment / Character of injury | Complete restoration | Significant improvement | Insignificant improvement | No change |
|---|---|---|---|---|
| Nerve and soft tissues | 2.1 | 16.3 | 19.9 | 61.7 |
| Nerve, soft tissues and vessels..... | 1.3 | 7.0 | 18.3 | 73.4 |
| Nerve and bone..... | 0.5 | 8.1 | 17.5 | 73.9 |
| Nerve, bone and vessels..... | 0 | 5.6 | 16.8 | 77.6 |

Table 32

Evaluation of the long term results of conservative treatment in firearms injuries to the peripheral nerves (in percentages)

| Result of treatment | Percent according to each group of results |
|---|---|
| Complete restoration of movement and sensitivity..... | 21.6 |
| Significant improvement in movement and sensitivity..... | 27.7 |
| Insignificant improvement in movement and sensitivity..... | 28.7 |
| Condition is unchanged..... | 19.2 |
| Deterioration of condition..... | 2.8 |

As we mentioned above, the effect of conservative therapy /359 depended, aside from other reasons, on the character of the injury. Table 31 shows the dependence between the degree of functional restoration and the character of the injury.

As we see from table 31, which was compiled according to the materials for the development of illness histories, as a result of complex therapy performed at the hospital for injuries of the nerve and the soft tissues, the percentage of improvement (complete restoration, significant improvement and insignificant improvement) is equal to 38.3%. In 61.7% of the cases, no improvement was noted in the hospital.

The effectiveness of the treatment gradually diminishes in the following order: with injury to the nerve, soft tissues and vessels the improvement comprises 26.6%, no change -- 73.4%; with injury to the nerve and bone, improvement comprises 26.1%, no change -- 73.9%; and finally, with injury to the nerve, bone and vessels the percent of improvement comprises 22.4%, while no change is noted in 77.6% of the cases (fig. 139).

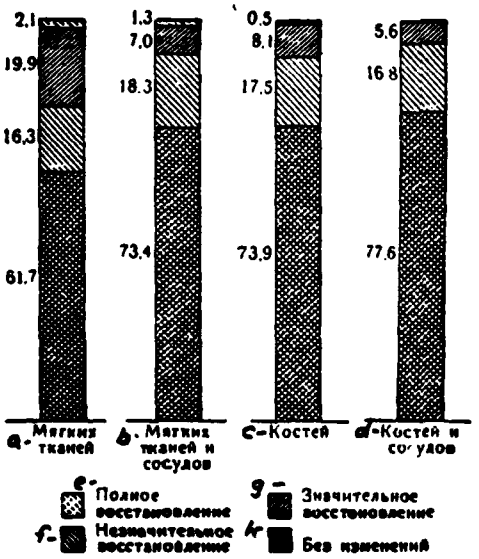



Fig. 139. Immediate results after conservative treatment of firearms injuries to the peripheral nerves in connection with the character of injury. a - Soft tissues; b - Soft tissues and vessels; c - Bones; d - Bones and vessels; e - Complete restoration; f - Insignificant restoration; g - Significant restoration; h - No change.

These are the immediate results of conservative treatment after injury to the peripheral nerves. However, a true evaluation of the conservative treatment performed in the hospital may only be given on the basis of considering the long term results of the treatment.

For this purpose, data observed as a result of repeated examination of wounded patients under hospital and polyclinic conditions were analyzed, as well as the data taken from records (a total of over 2,000 cases).

The following data (table 32) were obtained from an analysis of the materials for the development of illness histories, which characterize the results of conservative therapy.

As we see from table 32, the long term results of conservative treatment after firearms injuries to the peripheral nerves in 78% of the cases were characterized by a restoration to one degree or another of the lost functions. Here it should be noted that full restoration ensued in 21.6% of the cases, and only in 22.0% of the cases did conservative therapy not give any improvement (fig. 140). Such effectiveness of the conservative treatment of firearms injuries to the peripheral nerves may be explained by the system of medical evacuation aid rendered for these injuries. Physiotherapy and exercise therapy were used in early periods after the peripheral nerve injuries and were systematically performed, beginning with the army region.

Table 33 illustrates the long term results of conservative treatment according to the individual nerves with an observation time of up to 6 years. /360

From this table it is evident that the best therapeutic effect with conservative treatment was observed with injury to the femoral nerve, followed by the radial, ulnar, median and tibial. A significantly lesser effectiveness was observed with combined injuries to the nerve trunks. The least effective was treatment with injury to the sciatic nerve: its injury yielded the highest percentage (9.7%) of deterioration in condition.

From an analysis of the long term results of conservative therapy with firearms wounds to the peripheral nerves, certain regularities were discovered which reflect the effect of definite treatment methods on the dynamics of functional restoration (table 34).

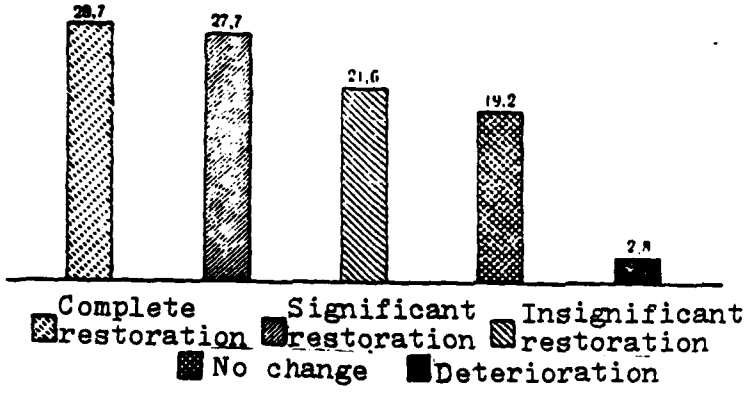



Fig. 140. Long term results after conservative treatment of firearms wounds to the peripheral nerves.

The data in table 34 show that the greatest therapeutic effect in the sense of restoring motor and sensory function was noted in the group of patients whose treatment complex included physiotherapy and exercise therapy from the very first days after the injury, and in patients subjected to operation -- from the first days after the operation (fig. 141).

As concerns the sequence of application of individual parts of this complex, the greatest therapeutic effect was obtained in the group of patients whose treatment was conducted according to the following scheme. Galvanization was performed daily: on the first day longitudinal galvanization was performed, and on the same day before galvanization the patient received either paraffin therapy or mud treatment; on the second day -- transverse iodine ion galvanization. Exercise therapy and massage were conducted daily before the galvanization. The number of procedures was 45-60, after which a break of 14-20 days was prescribed. After this time had elapsed, a second course of longitudinal galvanization and transverse iodine ion galvanization was performed. The patients performed exercise therapy for the entire time of their hospital stay.

The described complex gave the best therapeutic effect (as compared with other complexes) also in patients with old firearms injuries to the peripheral nerves (up to 7 years).

As a result of the complex methods of treatment presented above, in the acute as well as well as in the chronic period of the pathological process (up to 5-7 years), positive /361
shifts were noted not only on the part of the functions of the damaged nerve. In almost all cases it was possible to note positive shifts on the part of various systems of the organism: the tonus of the peripheral vessels, the condition of the vascular-connective tissue barriers, the blood biochemistry, the biological reactions of the skin to ultraviolet radiation, the ketoacid content in the urine, etc. Consequently, the described complexes of conservative therapy had a favorable effect not only on the definite symptoms of peripheral nerve injury, but on the entire pathological process developing in the given organism.

Table 33

Long term results of conservative treatment by individual nerves (in percentages)

| a - Название нерва / b - Результат лечения | c - Полное восстановление | d - Значительное функциональное улучшение | e - Незначительное функциональное улучшение | f - Без изменений | g - Ухудшение | h - Итого |
|---|---|---|---|---|---|---|
| i - Плечевое сплетение | 12.2 | 33.3 | 27.8 | 21.1 | 5,6 | 100.0 |
| j - Лучевой | 26,9 | 28,6 | 28.6 | 15,9 | — | 100.0 |
| k - Срединный | 25.0 | 22.1 | 32,4 | 17.6 | 2,9 | 100.0 |
| l - Локтевой | 26.2 | 30.1 | 28,1 | 14,6 | 1,0 | 100.0 |
| m - Лучевой и срединный | 19.1 | 29,8 | 27,7 | 23,4 | — | 100.0 |
| n - Локтевой и срединный | 19,7 | 24,6 | 31.1 | 23,0 | 1,6 | 100.0 |
| o - Лучевой и локтевой | 20.1 | 27,7 | 34,8 | 17,4 | — | 100.0 |
| p - Локтевой, лучевой и срединный | 12 6 | 31.2 | 39,4 | 16.8 | — | 100.0 |
| q - Бедренный | 44.5 | 33,4 | 9.1 | 13,0 | — | 100.0 |
| r - Седалищный | 13 8 | 21,5 | 30.0 | 25,0 | 9,7 | 100.0 |
| s - Малоберцовый | 15.1 | 28,3 | 31,2 | 22,6 | 2,8 | 100.0 |
| t - Большеберцовый | 16,7 | 33,3 | 33,3 | 16,7 | — | 100.0 |
| u - Малоберцовый и большеберцовый | 10.0 | 25,0 | 29,6 | 28,4 | 7,0 | 100.0 |

a - Name of nerve; b - Result of treatment; c - Complete restoration; d - Significant functional improvement; e - Insignificant functional improvement; f - No change; g - Deterioration; h - Total; i - Brachial plexus; j - Radial; k - Median; l - Ulnar; m - Radial and median; n - Ulnar and median; o - Radial and ulnar; p - Ulnar, radial and median; q - Femoral; r - Sciatic; s - Fibular; t - Tibial; u - Fibular and tibial.

Table 34

The results of conservative treatments (in hospitals) depending on the character of treatment (in percentages)

| a - Результат лечения / b - Характер лечения | c - Физиотерапия | d - Лечебная физкультура | e - Массаж и лечебная физкультура | f - Лечебная физкультура и бальнеотерапия | g - Лечебная физкультура и грязелечение |
|---|---|---|---|---|---|
| h - Полное восстановление движений и чувствительности | 26,7 | 20,3 | 24,6 | 19,5 | 24,2 |
| i - Значительное улучшение движений и чувствительности | 20,0 | 36,7 | 27,9 | 27,6 | 25,8 |
| j - Незначительное улучшение движений и чувствительности | 36,7 | 25,3 | 21,3 | 27,6 | 27,5 |
| k - Состояние без перемен | 16,6 | 17,7 | 26,2 | 23,0 | 19,2 |
| l - Ухудшение | 0 | — | — | 2,3 | 3,3 |

a - Result of treatment; b - Character of treatment; c - Physiotherapy; d - Exercise therapy; e - Massage and exercise therapy; f - Exercise therapy and balneotherapy; g - Exercise therapy and mud therapy; h - Complete restoration of movement and sensation; i - Significant improvement in movement and sensation; j - Insignificant improvement in movement and sensation; k - Condition remains unchanged; l - Deterioration.

Also interesting are the data obtained in the analysis /362 of results of treatment conducted repeatedly after discharge from the hospital, depending on the character of the therapy (table 35).

According to table 35, subsequent optimum therapeutic effect also with repeated conservative treatment (only 16.7% unchanged instead of 42.1% with other combinations) is given by the complex: physiotherapy, exercise therapy, massage.

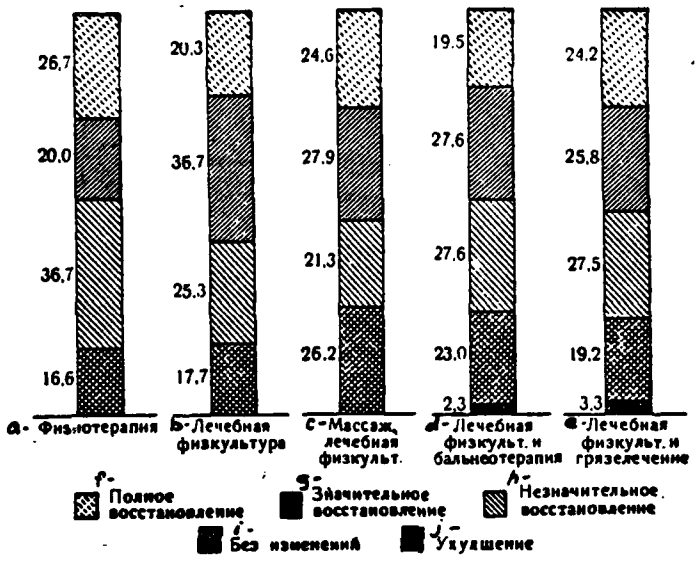



Fig. 141. Immediate results after conservative treatment of firearms wounds to the peripheral nerves depending on the character of the injury.

a - Physiotherapy; b - Exercise therapy; c - Massage, exercise therapy; d - Exercise therapy and balneotherapy; e - Exercise therapy, mud therapy; f - Complete restoration; g - Significant restoration; h - Insignificant restoration; i - No change; j - Deterioration.

Table 35

Results of conservative treatment (after discharge from the hospital) depending on the character of treatment (in percentages)

| Result of treatment \ Character of treatment | Physiotherapy, exercise therapy, massage | Other combination of forms of treatment |
|---|---|---|
| Complete restoration of movement and sensation..... | 16.7 | 21.0 |
| Significant improvement in movement and sensation..... | 33.3 | 15.8 |
| Insignificant improvement in movement and sensation..... | 33.3 | 21.1 |
| Condition remains unchanged... | 16.7 | 42.1 |
| Deterioration of condition.... | -- | -- |

In solving the problem of the expediency of repeated courses of physiotherapy in cases of a very old pathological process, much interest is presented by the analysis of data obtained in the development of material for illness histories with a time after hospital discharge ranging from 1 year to 7 years (table 36).

Table 36 /363

Long term results after conservative treatment depending on the time of observation (in percentages)

| Result of treatment \ Time of observation | 1 yr. | 2 yrs. | 3 yrs. | 4 yrs. | 5 yrs. | 7 yrs. |
|---|---|---|---|---|---|---|
| Complete restoration of movement and sensation... | 45.4 | 18.0 | 20.9 | 16.8 | 25.7 | 32.9 |
| Significant improvement in movement and sensation... | 27.3 | 25.0 | 28.4 | 24.9 | 30.9 | 32.9 |
| Insignificant improvement in movement and sensation... | 9.1 | 32.7 | 28.4 | 34.5 | 28.3 | 12.2 |
| Condition unchanged..... | 18.2 | 20.5 | 18.4 | 21.5 | 13.8 | 20.8 |
| Deterioration..... | -- | 3.8 | 3.9 | 2.3 | 1.3 | 1.2 |

As evident from table 36, repeated courses of complex conservative treatment repeated over a number of years give a definite stable therapeutic effect even when the pathological process is very old.

The presented factual material of immediate as well as long term results of conservative treatment for peripheral nerve injuries speaks of its great therapeutic effectiveness (from 70.0 to 80.0% improvement).

The experience of conservative therapy in firearms injuries to the peripheral nerves has shown that one of the important achievements of the Soviet Army Medical Service in the period of the Great Patriotic War was the proximation of specialized aid immediately next to the troop area. The army hospital base had a sufficient physiotherapeutic equipment which enabled the performance of complex conservative aid in early periods with peripheral nerve injuries.

For the first time in the history of war was such clearly and widely implemented complex physiotherapy applied in peripheral nerve injuries during the Great Patriotic War. It was characterized by its timeliness and applicability of implementation at all stages of evacuation.

All this facilitated the earlier functional restoration of the damaged nerve trunks and made it possible for a large number of soldiers to return to the ranks of the Soviet Army and for almost all to return to peacetime labor.

## CHAPTER VI

## THE CLINICAL PICTURE AND TREATMENT OF REFLEX CONTRACTURES AND PARALYSES DEVELOPING AFTER FIREARMS INJURIES TO THE PERIPHERAL NERVES

Symptomatology and clinical description of reflected complications developing in connection with firearms injuries to the peripheral nerves.

Neuropathologists paid particular attention to these forms /364 during the First World War, when they began to describe unique syndromes which did not fit either into a clear picture of injury to one single nerve or into the picture of psychogenic, hysterical disorders.

The study of these unique conditions led to the classical description given by Babinskiy and Froman, who designated these conditions as "nervous disorders of a reflex nature" or as "physiopathic disorders".

The traumas causing these syndromes were often light and did not affect the large nerve trunks. Three types of these syndromes have been isolated: 1) paralysis with contractures, 2) reflex contractures and 3) reflex paralysis.

The contractures developed for the most part in distal regions of the extremity, giving the upper extremity the position of "obstetrical hand", etc. Extension and flexional contractures of the hand and fingers were observed; on the lower extremity, pes varus or pes equino-varus and flexional and extensional contractures in the knee joint often developed. Efforts to overcome the contractures were accompanied by pains. With the application of Esmarch's bandage they disappeared in a few minutes for a while. Passive movements, massage and exercise aggravated them. The tendinous reflexes and mechanical excitability of the muscles was increased, the latter particular-

ly after cooling the extremity. Under mild narcosis, these contractures, unlike those of hysterical character, did not relax for a long time. The muscles atrophied quite rapidly, but without qualitative changes in their electroexcitability. Sometimes quantitative increase in galvano-excitability was noted. Sensitivity was altered without correspondence with zones of peripheral innervation. Deep changes in trophics were always apparent: hypertrichosis, thinning of the skin, trophic changes in the fingernails, cicatrical wrinkling of the aponeuroses, coldness of the extremity, cyanosis, hyperhydrosis, osteoporosis. Often there were combinations with hysterical stratification (hystero-reflex syndromes). Reflex hypotonic paralysis was observed less frequently than reflex contractures. Reflex paralysis of the extensors of the hand and fingers reminiscent of paralysis in radial nerve injury /365 were observed with particular frequency.

The stability of these disorders is characteristic. Ordinary psychotherapeutic methods did not eliminate them, as well as physiotherapeutic procedures. These patients were distinguished by a unique flaccidity, reticence, which is why they were sometimes mistaken for hysterics, agravants, or even malingerers.

According to Babinskiy and Froman, the basis for these conditions is the reflex stimulation or inhibition of the nerve centers under the influence of the irritating focus at the periphery. It is possible that the reflex spasm of the vessels plays a pathogenetic role in the realization of locomotory disorders.

These explanations were quickly adopted by neuropathologists, but many other explanations and hypotheses also appeared.

While a number of neuropathologists favored the hysterical origin of these syndromes, M. I. Astvatsaturov (1935) was of the opinion that the basis for these contractures were physiopathic disorders. However, he rightly pointed out that in certain forms of hysterical contractures it is possible to have a clinical picture which looks very much like the syndrome of an actual reflex contracture.

The Great Patriotic War again acutely presented this as yet underdeveloped chapter of neuropathology. The question of reflex contractures and reflex paralysis began to particularly interest physicians, since most of them did not know at first how to precisely diagnose these conditions or how to treat them. Here, significant differences of opinion became apparent in the understanding of these syndromes.

In order to understand the following, from the very beginning we must keep in mind that here we will be speaking not of individual strictly limited traumatic illnesses, as are "reflex contracture", "reflex paralysis" and others, but of the individual components of complex clinical pictures. The latter often present a combination of a number of rather varied combinations when, for example, in one set of muscle groups the syndrome of direct loss of a nerve may be determined, and in others -- the syndrome of reflex contracture, in a third set -- cicatrical contractures, and in a fourth -- contomitant paralysis, etc., and all this in the same wounded extremity.

## Reflex contractures

Injuries leading to the development of reflex contractures, in the opinion of most authors, are primarily located distally. On the upper extremity this is most often an injury of the middle and especially the lower third of the forearm and hand (S. N. Davidenkov, Ya. M. Balaban). Distally from this level,

i.e., in the region of the fingers, these injuries are already observed more rarely. Thus, a characteristic of these injuries is a favorite localization -- most often this is an injury of the lower third of the forearm located somewhat proximally of the radiocarpal articulation, primarily close to the midline, between the bones of the forearm. A. Yu. Sozon-Yaroshevich, out of 65 patients with reflex contracture of the upper extremities, found a primary focus in the area of the radiocarpal articulation and the interosteal ligament in 43 of those patients. A similar localization was noted by Yu. M. Uflyand and Yu. V. Vasilenko. In these cases it was already to anticipate ahead of time the frequent injury to the median nerve, as well as the dorsal and volitional nerve of the forearm. However, a reflex contracture may also arise without injury to these nerves. It is important to /366 compile the frequency of this localization with the analogous frequency of injuries of different localization with causalgia, in which on the contrary the frequency of injuries clearly diminishes in the direction toward that area where it is highest with reflex contracture.

According to the materials for the development of illness histories, reflex contractures were noted in 0.5% of the cases of all peripheral nerve injuries. Clarified here was a corresponding frequency of reflex contractures conditioned by injury to the corresponding nerves (table 37).

It is evident from table 37 that reflex contractures were observed most often in injuries to the femoral, median, sciatic, fibular, tibial and ulnar nerves.

There were differences of opinion regarding the frequency of nerve injuries with reflex contractures.

Table 37

The frequency of reflex contractures with injury to the individual nerves

| Name of nerve / Percent of relation of frequency in reflex contractures to all injuries of the individual nerve | Percent |
|---|---|
| Brachial plexus | 0.2 |
| Radial | 0.2 |
| Median | 0.7 |
| Ulnar | 0.7 |
| Median and radial | 0.1 |
| Median and ulnar | 0.5 |
| Femoral | 1.7 |
| Sciatic | 0.7 |
| Fibular | 0.2 |
| Tibial | 1.5 |
| Nerves of the leg | 0.8 |

Numerous authors believed that the initial focus of irritation in the formation of reflex contractures and reflex paralysis may be not only the nerve injuries, but also injuries to the muscles, tendons, ligaments and bones.

Out of 73 patients, A. Yu. Sozon-Yaroshevich found damage to bones or interosteal ligaments in 38 of them; these were the wounded patients who did not have injuries to the major nerve trunk. However, this fact only indicates that bone tissue is richly supplied with nerves which not only branch along the surface of the bone, but also penetrate inside the bone. Moreover, a considerable part of them contains center-directed fibers. Approximately 30% of the cases of reflex contractures were also complicated by injuries to the vessels. Injury to the major nerve trunks was established in 56 patients. However, since in the cases with injury to the major nerves as well as in the cases without injury to the major nerves

there was complete correspondence in all else, it would be natural to consider, according to A. Yu. Sozon-Yaroshevich, that this similarity is explained by the participation of the conductive paths of the vascular and osteal innervation in the major nerve trunks.

T. N. Klekova conducted a detailed study of the topography of nerves which supply the bones, the periosteum, and the articulatory bursae of the proximal region of the hand. Part of the branches supplying the bones diverge from the cutaneous /367 branches of the forearm. It turned out that any major nerve trunk of the upper extremity contained a certain number of nerve fibers which lead to the bones of the hand. These data, if we allow in the genesis of the reflex contracture the primary injury to deep sensory nerves, would allow us to explain why totally similar syndromes develop sometimes with trauma to the more proximal regions of the upper extremity, as well as with injury to the cutaneous nerve branches on the forearm.

If it is necessary to assume that in all cases of reflex contracture the participation of the nerve is mandatory, and that in injuries to the bones the starting mechanism of the syndrome consists in the actual irritation of center-directed fibers of the osteal nerves, then injury to one of the three "major" nerves of the upper extremity is by far not necessary. According to the materials of personal observation, the latter were noted in less than half of all the cases (out of 25 reflex contractures of the upper extremity, injury to the major nerve trunks took place in only 11). According to the data of A. Yu. Sozon-Yaroshevich, injuries to one or another nerve trunk are constantly being found during surgical revision. On the upper extremity, injury to the dorsal and volitional interosteal nerves of the forearm is found with particular frequency, and on the lower extremity -- injury to the deep fibular nerve and branches of the tibial nerve (on the crus).

Simultaneous firearms bone fractures are by far not mandatory. According to the materials of personal observation, they were noted in one-third of all cases, while injuries to the vessels were noted even more rarely.

A rather peculiar position in regard to the origin of the reflex contracture was taken by A. G. Molotkov, who indicated the special role of injury to the cutaneous nerves in the genesis of reflex syndromes.

V. L. Lesnitskaya also notes the frequency of the reflex contracture with painful scars in the area innervated by the cutaneous nerves of the forearm.

In connection with the conception of A. G. Molotkov, interesting facts were reported by N. A. Popov. He presented a comprehensive summary of the data on his patients suffering from reflex contractures and paralysis. Out of the 50 patients, 35 had undergone operations. All of the operated patients except two exhibited injury to one of the cutaneous nerves. Most often on the upper extremity, the superficial branch of the radial nerve was affected, sometimes in combination with the external cutaneous nerve of the forearm, while on the lower extremity the cutaneous branches of the superficial fibular nerve were affected. The removal of the scars and neurotomy of traumatized nerves had a favorable effect on the course of the reflex syndrome.

Thus, we must acknowledge with certainty that it is specifically the injury to the peripheral nerves which serves as the irritating local focus which leads to the development of the reflex contracture. As concerns the cutaneous nerves, from a comparison of the literary data and the materials of personal observation, there is no impression of any particular frequency of their injury. In this respect there is a certain difference between the reflex contracture and reflex flaccid paralysis. It is specifically in this second group, evidently,

that clear injuries to the cutaneous nerves are observed (N. A. Popov).

The clarification of the role of over-stimulation of the deep sensitivity conductors in the genesis of the reflex contracture has forced us to approximate it with the unique vegetative-trophic "syndrome of hand injury" which develops in trauma to the dorsal interosteal nerve of the forearm.

This syndrome, which was studied by Soviet neurosurgeons as early as the pre-war period (A. G. Molotkov, A. L. Polenov, G. I. Turner, L. A. Shil'nikov and others), is in many ways similar to ordinary reflex contractures, and some authors (B. S. Doynikov) describe them together. This syndrome should be examined as one of the sub-types of common reflex syndromes. However, it does have a unique clinical characteristic description. It was necessary to reject the primary assumption that the reflex contracture is formed only after a more or less lengthy period following the injury. A significant number of patients definitely noted that the pathological pose developed either immediately after the injury was sustained, or very soon thereafter. However, in some patients the reflex contracture syndrome was actually established only later or subsequently became intensified. /368

A characteristic indication of the reflex contracture is increased muscle tonus with passive movements, i.e., hypertonia of the afflicted muscles.

The reflex contracture in this respect also differs sharply in principle from the cicatrical, ischemic and immobilizing contractures, in which the muscle tonus is not elevated within the limits of the possible volume of passive movement. These latter contractures are for the most part "retractions", while the reflex contracture is a "spasm".

Fig. 142. Reflex contracture of the digital flexors after an open bullet wound at the boundary of the lower and middle third of the left forearm with injury to the radius without objective disruptions in sensitivity.

The degree of tonus elevation in the reflex contracture varies within considerable limits -- up to the degree of fine arhythmic clonus of spasmodic muscle contractions. The increase in tonus during passive movements is also noted in the hysterical contracture, which makes diagnosis somewhat difficult. However, the experienced neuropathologist may identify hysterical hypertonia, which bears all the marks of arbitrary muscle tension, simply by the feel in overcoming the muscle spasm.

The pose in which the extremity is frozen may be extremely /369 varied, particularly since part of the deformations may often be related to simultaneously existing cicatrical retractions. Nevertheless, the hand and fingers most often take on the

position of the "obstetrical hand" or are compressed into a fist (fig. 142).

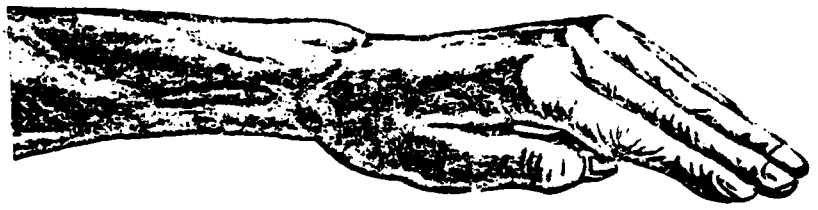


Fig. 143. Open fragmentary wound to the lower third of the left forearm with fracture of the radius and injury to the superficial branch of the radial nerve. The reflex contracture is in a position of flexion of the fingers in the primary phalanges, extension of the fingers in the interphalangeal joints, and adduction of the fingers.

The first of these variants is a result primarily of the spasm of the interosteal muscles. The palm is bent inward, the fingers are in a state of adduction, metacarpo-phalangeal flexion, and more or less significant inter-phalangeal extension (fig. 143). The index finger in this case is often brought under the III finger, and the fifth finger -- under the IV (fig. 144). The tendon-ligament retraction which soon ensues in the interphalangeal joints hinders efforts at interphalangeal flexion of the fingers, which is always particularly painful. The hand, compressed into a fist, is the result of the primary spasm of the superficial and deep digital flexor and flexor of the thumb. Sometimes the spasm of the interosteal muscles and flexors occurs simultaneously, and then even more severe deformations

are formed. The I finger may be positioned in a pose of spasmodic adduction (fig. 145).

These contractures of the fingers are often complicated by heavy contractures in the radiocarpal articulation in the position of flection of hand or its abduction, or extension (Fig. 146).

Fig. 144. Reflex contracture of the muscles adducting the fingers and the flexors of the hand with an open wound in the lower third of the forearm.

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Fig. 145. Spasmodic opposition of the thumb with reflex contracture.

Often the movements of only the II-V fingers may be disrupted, with relatively well retained movements of the

thumb. The reverse relations or isolated spasm of the I and II finger, etc. were noted less frequently. These dissociated digital syndromes in combination with a contracture in the radiocarpal articulation sometimes create rather odd positions.

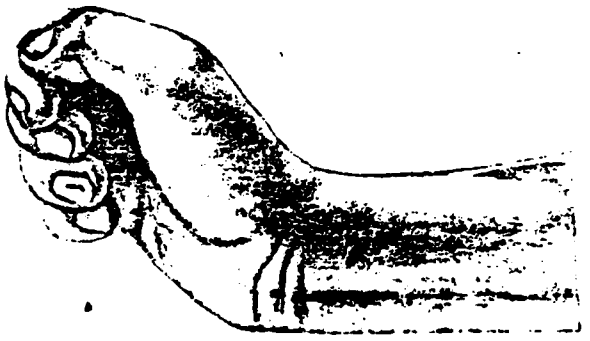

Fig. 146. Combined reflex contracture of the hand extensors and digital flexors with an open (through) bullet wound to the lower third of the forearm.

Often hypertonia spreads in a proximal direction, and rotation of the arm and uplifting it may be difficult. Diffuse wasting of the proximal sections of the extremity are also frequent.

In studying these different poses, we were able to observe how in the course of the illness one type of contracture is replaced by another. Thus, the immobilization of the fingers in a straightened position led to the development of a spasm in the interphalangeal extensors, which was /371 subsequently gradually replaced by the previous flexor position. From this we must draw the following conclusions: first of all, with one and the same localization of injury, the development of various spastic poses is possible; secondly,

the reflex fixation of these poses may be influenced by the position given to the extremity.

There were also differences of opinion on the question of the condition of reflexes in the reflex contracture. To a considerable degree this is explained possibly by the fact that the reflexes which should be given attention are not always the ones studied. Often all three of the commonly studied reflexes on the upper extremity turn out to be normal, while the tendinous reflexes on the muscle which is in the state of contracture may be noticeably increased. Thus, there is often a clearly increased reflex from the tendons of the digital flexors, as well as the reflexes on the interosteal muscles, which for the most part are not registered in the norm. An increase in the mechanical muscular excitability is also noted with this syndrome. The latter may very well be found on the short palmar muscle. Certain authors also noted an increase in the mechanical excitability of the peripheral nerves.

Sometimes it is possible to observe in the contractured muscles something akin to actual clonus, although not so prolonged and rhythmic as in affliction of the pyramidal path, although quite painful. Corresponding to this in a less expressed degree are small saccadic jolts which are noticeable in efforts to overcome the contracture. Often fascicular tremor is observed in spastically contracted muscles. The development in the interosteal muscles of such fascicular contractions, which cannot be voluntarily produced, confirms the physiopathic nature of the disorder.

In regard to the degree of retention of muscle force in the reflex contracture, it should be kept in mind that here, of course, there is not only the contracture, but also

the paralysis or at least the deep paresis of the musculature. In part of these patients, active movements in the contractured muscles are totally absent. In other cases, the ability to preserve some, though always limited and retarded, active movement is retained.

Such spastic paralysis or paresis in one set of muscle groups may be combined with flaccid reflex paralysis in other groups, which indicates a certain proximity of both syndromes. This proximity is also indicated by the fact that if by means of one or another surgical intervention it becomes possible to eliminate the reflex contracture, the reflex paralysis sometimes remains in its place. There are, however, considerations which testify to the fact that the intimate mechanism of both syndromes, despite their closeness, is not identical. Thus, preganglionar sympathectomy does not eliminate flaccid reflex paralyses in which, moreover, there is no characteristic localization of the injury which is inherent in the reflex contracture syndrome.

In reflex contracture in the regression phase, it has been possible to discover one clinical detail. Sometimes the patient, being already able to bring his hand and fingers out of the habitual defective position, nevertheless cannot retain them in this new position for any length of time. In one such case we were able to clarify the intimate mechanism of this symptom: it turned out that the patient, bringing the hand and fingers out of the contractured position, held his breath and could hold the fingers straight only while he was not breathing. However, with the first respiratory /372 movement the spasmodic position was once again restored. It turns out that a single irradiation from the respiratory musculature was enough to again set in motion the overstimulated reflex mechanism.

Of course, there are never and qualitative changes in electroexcitability with the reflex contracture (with standard study by galvanic and faradic current). Often an overall wasting of the musculature is observed.

Disruptions in sensation with reflex contractures represent for the most part diffuse hypesthesia or anesthesia which encompass the distal regions of the extremity, often bounded by circular lines reminiscent of the form of a "sock" or "glove". At one time this form of sensitivity disruption was unquestionably considered by physicians to be a sign of hysteria. Today these forms of sensitivity disruption are well known, and are observed in cortical foci as well as in certain spinal cord injuries, which for us presents particular interest in injury to the sympathetic chain. The upper limits of sensitivity disruption is often blurry, and the field of anesthesia only gradually changes into the zone of normal sensation. The sensation of passive movements may also be disrupted. Sometimes hyperpathy is observed. Often on a background of this diffuse hypesthesia there is a zone of deeper anesthesia which corresponds to the area of the directly damaged nerve. Often the hypesthesia is distributed in a more or less long strip extending along the length of the extremity (on the arm corresponding to its ulnar or radial margin) and with a dissociated contracture which often corresponds with the primarily afflicted fingers. Spontaneous pains rarely enter into the picture of a reflex contracture. Soreness is usually noted in any effort to overcome the contracture.

The vegetative-trophic symptoms which complicate the reflex contracture are extensive and mandatory. Among them is hyperhydrosis, swelling of the hand, hypertrichosis, hyperkeratosis, abnormal growth and dystrophy of the fingernails, atrophy of the skin and subcutaneous fatty tissue with formation

of conical, as if "sucked" fingertips, cyanosis or erythrosis, osteoporosis, trophic tendon-ligament retractions which rapidly fix the segments of the extremity, particularly the fingers, in a pathological position, and cicatrical wrinkling of aponeuroses up to the formation of actual Dupuytren's contracture. The degree of expression of these vegetative-trophic symptoms varies. In individual cases they reach such intensity that they even overshadow the syndrome of the reflex contracture.

Contradictory data have been obtained concerning the changes in the reflex contracture during narcosis. This is evidently explained not only by the different methodoloty of study, but also by the non-uniform selection of cases. S. N. Davidenkov, S. V. Gol'man, P. M. Saradzhishvili described cases of contracture retention under light narcosis, while S. I. Zil'berberg felt that for patients with a reflex contracture, relaxation of the contracture was characteristic under raush narcosis. The same was noted by Ya. M. Balaban, B. E. Levi and Z. Ya. Rabkin, who indicated that ether desensitization leads to a temporary improvement which, however, disappears after several days. The effect of deep narcosis in relaxing the contracture was also indicated by G. D. Aronovich and M. S. Zhukhovitskiy.

The fact that the reflex contracture is most often noted in neurotics is almost unanimously noted by all those who observed these patients, and this cannot be refuted with the single correction that this combination is by far not mandatory. There were wounded patients with a typical reflex syndrome who were completely calm, well-balanced, and with completely organized behavior. It is possible that the inclination of the sympathetic system to give widespread irradiations lies at the basis of the reflex contracture as well as the general nervousness of the subject. /373

Alongside this we must pose another question: how can we explain the fact that the reflex contracture is observed "only in wartime"? We must, however, consider in the first place that under wartime conditions there may easily be three specific stimulators of the sympathetic system in various combinations: cold, pain and emotion. Secondly, doubts arise as to whether reflex syndromes are really so closely associated exclusively with wartime. If they are not readily apparent in peacetime, this is evidently explained simply by the rarity of firearms injuries during peacetime.

Much has been accomplished by Soviet neuropathologists in clarifying the intimate pathogenesis of the reflex contracture. The most valuable contribution to the study of the pathogenesis of reflex contractures was made by A. M. Grinshteyn.

A. M. Grinshteyn began with the study of the symptomatics of injury to the marginal sympathetic trunk. Here he was able to discover sensitivity disorders bounded by transverse margins, tonus disruptions leading to the appearance of various deformations (for example, the "obstetrical hand"), numerous disruptions in the vasomotor, pilomotor and secretory function of the skin, as well as trophic disorders of the skin, its annexa, the subcutaneous fatty tissue, the joints and the fascia. These symptoms of direct illnesses or traumas to the marginal trunk were naturally associated with the reflex contracture. In 1944, A. M. Grinshteyn presented an analysis of the reflex contracture from this point of view. Reflex contractures temporarily improved after paravertebral block of the connective branches of the marginal trunk at the level of the V, VI and VII thoracic vertebrae and disappeared after resection of the third thoracic sympathetic node ("pre-

ganglionar sympathectomy" -- an operation whose advantages were pointed out in the treatment of causalgia by A. M. Grinshteyn as early as 1939). The afferent arch of this reflex, in the opinion of A. M. Grinshteyn, is formed from the visceral receptor fibers entering the spinal cord at the level of the sympathetic cells which correspond to the lateral cornua (for the brachium -- from the fourth to the seventh thoracic segment).

Various syndromes, including also causalgia, represent a specific nosological unit -- "the reflex spinal-truncusal syndrome". The direct result of this concept was a series of therapeutic measures which proved the correctness of this interpretation.

This view of the nature of the reflex contracture, whose basis is a stable, fixed vegetative reflex implemented through the cells of the lateral cornua of the spinal cord and through the cells of the sympathetic marginal trunk, is shared by a number of neuropathologists working during the course of the Great Patriotic War on the problem of reflex contractures (A. Yu. Sozon-Yaroshevich, S. N. Davidenkov and others).

A unique concept for understanding the essence of the reflex contracture was proposed by A. I. Geymanovich. He presents the question, doesn't the combination of peripheral conditions and peripheral vegetatics with the central, maybe /374 extrapyramidal, conditions play a role here? In contradiction to most other authors, A. I. Geymanovich stresses the importance of direct peripheral irritation of the afflicted nerve, leading to tonic spasm of the musculature.

N. N. Pyatnitskiy also speaks of "irritative neuritis" which is the basis for physiopathic contractures.

D. I. Panchenko unites reflex contractures and paralyses under the common name of "syndrome of post-traumatic dysfunction" of the distal region of the extremity, and in regard to the pathogenesis of these disorders gives particular attention to ischemia. "Ischemic neuritis", according to the author, is the basis for reflex syndromes.

D. G. Shefer and M. E. Kolik, analyzing the reflex contracture syndrome at various stages of its development, came to the conclusion of its irritative-reflective genesis in the first phases of the syndrome's development. Subsequently, however, a unique degenerative process develops in the nerve itself, which is something akin to a muted form of ascending vegetative neuritis. In the concluding phase of the process, the position of the extremity is already determined by the processes of wrinkling which develop around the joints.

D. K. Bogorinskiy also assumes that the periarterial sympathetic plexuses are also involved in the process. Such perivascular sympathetic neuritis may spread in a proximal direction. However, in a number of cases the syndrome is too widespread, and these cases, according to the author, may already have a true reflective origin.

M. S. Margulis and M. K. Usova have presented a unique hypothesis, according to which reflex neurovascular reactions develop near the injury which disrupt the blood circulation in the muscle. Moreover, deep changes in the intra-tissue metabolism arise in the muscles, which is primarily reflected on the most sensitive organ -- on the synapses. This hypothesis has as yet not been confirmed histologically. With this interpretation it would be difficult to understand the origin not only of paralyses, but also contractures, the disappearance of the contracture after destruction of the sympathetic reflex arch, as well as the paradoxal non-

correspondence between the condition of force and the reflexes. Moreover, for reflex syndromes it is not at all necessary to have the participation of the muscles which are closest to the area of injury.

N. M. Itsenko developed a particular point of view, maintaining that at least part of the cases related to those syndromes which Babinskiy called physiopathic depent on cicatrical compression or neuroma formations stemming from glomi vasculosi. It is possible, however, that the author's cases clinically differed somewhat from typical cases. In any case, these observations necessitate presenting the question on the possibility of certain clinical sub-types within the large group of reflex syndromes.

Many authors again raised the old question on the role of psychogenia in the genesis of physiopathic syndromes.

S. V. Gol'man gave primary importance to the psychical factor in the origin of reflex contractures and paralyses with particular insistence. He concentrated his attention only on those cases in which nerve damage was absent and which he determined as "so-called reflex contractures and paralysis", considering them essentially to be hysterical syndromes, "false" contractures and paralyses. As the basis for this reasoning, S. V. Gol'man used the positive effect which he obtained from persistent single-moment psycho- /375 therapy in conjunction with faradization. The studies of S. V. Gol'man may probably be viewed as going outside the framework of the given question, were it not for the fact that he had in mind the same reflex syndromes which were described by Babinskiy and Froman and he tried to apply his reasoning to this entire group.

The conception of S. V. Gol'man was subjected to criticism on the part of N. S. Chetverikov, who felt that S. V. Gol'man was dealing with hysterical forms which were only close in their clinical manifestation to reflex syndromes. The positions of S. V. Gol'man were very sharply discussed at the meeting of the Moscow Society of Neuropathologists and Psychiatrists on 5/31 1944. The proponents of both sides presented a large number of facts, but were unable to convince each other.

Most of the facts gathered during the time of the Great Patriotic War, however, necessitate strictly distinguishing the reflex contracture from hysterical disorders. This is also indicated in the "Instructions for Treating Reactive Traumatic Syndromes" of the General Administration for Evacuation Hospitals of the USSR Narkomzdrav.

A number of authors, while recognizing the true reflex nature of the described disorders, at the same time concede that the psychogenic mechanism also plays a significant role in them. Thus, Ye. K. Sepp and his colleagues attribute great significance to the psychical factor in the origin of reflex syndromes. Emotions facilitate the appearance of sympathetic symptoms under the influence of irritation at the point of injury, particularly under the influence of scars in the area of the joints and the periosteum. The role of the emotive factor in the origin of the syndrome is confirmed by the fact that the illness process begins to gradually subside when the patient is transferred to a peacetime position.

G. D. Aronovich and M. S. Zhukhovitskiy also feel that the reflex contracture develops as a "habitual contracture" from an anthalgic contracture, particularly in neurotic subjects. This is one of the forms of hysterotraumatism, but is not purely a psychogenic illness, but a "physiogenic-psychogenic, combined sometimes with organic injury to the

animal and vegetative peripheral nervous system".

I. S. Kudrin assumes the possibility of the multiple formation of these syndromes, different in all these cases. They may be classified according to two indicators: either by the time of development or by the level of the reflex which is the basis for the syndrome. According to the first indicator they are divided into the protective-anthalgic stage, into the stage of pathological fixation, and into the stage of secondary changes. According to the second indicator -- into vegetative, spinal, trunkal forms with predominance of the red nucleus mechanism, as well as into subcortico-thalamic and cortico-subcortical. The latter are usually designated as hysterical contractures. I. S. Kudrin calls these syndromes "large" reflex syndromes, rightfully pointing out that some less expressed "small" reflex component is observed in injuries to the peripheral nerves of the extremities much more often than is commonly supposed.

The differences of opinion regarding the role of the psychogenic factor in the origin of the reflex contracture are rather considerable and are evidently explained first of all by the fact that hysterical fixation before the real syndrome often takes place here also; secondly, by the fact that long-term over-stressing of the sympathetic nervous system which is characteristic of wartime conditions may facilitate the emergence of sympathetic syndromes, at the same time increasing also the general nervous excitability, /376 which is the basis for recognizing hysteria or some other stable neurosis in these cases.

In any case, the frequent combination of reflex and neurotic disorders is one more point in favor of the position

that in the sphere of nerve pathology, as well as in other divisions of medicine, we have the right to speak of purely "local" processes. Any local irritation is inevitably accompanied by a far-reaching repercussion which changes the aspect of the nerve function up to the higher neural activity. The higher neural activity which is disrupted due to one reason or another in turn affects the condition of stimulation or inhibition of lower stages of the nervous system. Thus is implemented the constant interaction of functions of the cortex and the peripheral regions, which is clearly expressed also in a number of observations dealing with reflex syndromes in injuries to the peripheral nerve trunks and which explains the abundance of "neurotic" disorders in patients as well as the favorable effect of general calming of the nervous system on the course of this syndrome.

In regard to the pathogenesis of the reflex contracture, we may now consider it an established fact that as a result of prolonged irritation of an afflicted peripheral nerve trunk, most often one of deep sensitivity, there is formed a stable, fixed reflex expressed in muscle spasm, in the reduction of sensitivity, and in complex vegetative disgunctions. A new element in understanding the paths of this reflex was the experimentally confirmed role not of the animal centers of the spinal cord, but specifically the sympathetic nervous system, the destruction of whose arch in the form of preganglionar sympathectomy or novocaine block eliminates the contracture (A. M. Grinshteyn). It has not yet been conclusively established whether the primary role belongs to the inclusion of afferent or efferent sections of this arch, or the simultaneous inclusion of both. The effect of overstimulation of the sympathetic nervous system on the tonus of the musculature should be understood in the sense that here

we have an example of the influence of the sympathetic nervous system on the animal in light of the data of L. A. Orbeli on the adaptational role of the sympathetic nervous system. The entire reflex is thus not exclusively vegetative, but vegetative-animalistic.

The question of differential diagnosis of the reflex contracture turned out to be extremely difficult. With careful study it is not difficult to distinguish it from the cicatrical contraction, for which more or less massive retractions are characteristic, but without hypertonia. It is easier to confuse it with the ischemic contracture, with which attempts have sometimes been made to unite it. Actually, both conditions are characterized by diffuse hypesthesia and the presence of vegetative-trophic symptoms. However, in the ischemic contracture, aside from the changes in the arteries, there is observed a characteristic thickening of the muscles, which is absent in the reflex contracture, and hypertonia is not observed. Within the limits of the volume of passive movements which are still possible, the tonus is not elevated and active movements are possible.

It is much more difficult to establish a differential diagnosis of the reflex contracture and hysteria. Here we must stress first of all that the genesis of the actual reflex contracture is neither psychogenic nor hysterical. The typical nature of the injury, the stability of the syndrome, the hyperreflexia, and the apparent effect of desympathization -- all these factors force us to consider the syndrome to be not a "psychopathic", but a "physiopathic" one. The greatest mistake would be to see some kind of "transition" between /377 the organic and the hysterical in such syndromes. These are two types of phenomena which are qualitatively deeply varied.

The difficulty in diagnosing consists primarily of the fact that in hysteria conditions reminiscent of the reflex contracture are possible and secondly of the fact that the reflex contracture subsequently often begins to take on hysterical overtones.

The similarity of the hysterical contracture with the reflex is, however, purely external. Inherent in hysteria, as always, is the greater polymorphism of the syndrome, which is not limited strictly to a definite and constant muscle territory. Anesthesia with boundaries which are easily shifted by means of suggestion, absence of acute vegetative-trophic indicators, normal reflexes and mechanical muscle excitability, disappearance of hypertonia in a state of narcosis and a general hysterical personality background are all immediately apparent. By its manifestation, hysterical contracture in no way differs from a volitional (or simulated) spasmodic tension of the musculature.

It is more difficult to establish the diagnosis in those cases when in the subsequent course a reflex contracture, gradually diminishing, begins to be replaced by an auto-suggested hysterical fixation of the extremity in the previous spastic position. The abundance of these cases is evidently the reason for differences of opinion as to the nature of the reflex contracture. Hysterical symptoms develop here according to the mechanism of "autoimitation" (self imitation), which is why the syndromes which are formed in this manner may become very similar to the actual reflex contracture.

Numerous attempts at treating the reflex contracture have yielded positive results. Undoubtedly, successful treatment here was facilitated by a better understanding of the

pathophysiology of these conditions. Thus, it is fully understandable that until the irritative focus is liquidated, any local passive movements, exercise and physical therapy are not borne well by the patient, who usually stubbornly refuses them. On the other hand, in those cases when the irritation is overcome, the same procedures are extremely valuable. Interventions at the point of the actual injury which facilitate the elimination of the focus of peripheral irritation, the removal of painful neuromas and scars, neurotomy, alcohol injections into the peripheral segment of the damaged nerve, the removal of centers of osteomyelitis, novocaine blocks, the application of a stable anode and other measures all have a favorable effect, although often they only reduce the intensity or extensiveness of the contracture without completely eliminating it. The positive effect from these interventions is better the earlier they are applied after the injury. The assumption of a fixed reflex which is the basis for the syndrome with its considerable irradiation explains the effect which is sometimes observed from novocaine block of a section of the healthy extremity symmetrical to the area of injury. Finally, intervention on the sympathetic nervous system may rapidly liquidate the contracture.

Without stopping on the special questions of reflex contracture therapy, we must stress the fact that this syndrome as become subject to treatment to a certain degree. "The reflex contracture is curable". This is the basic conclusion reached by A. Yu. Sozon-Yaroshevich. In these attempts one should never forget the above-mentioned hysterical-reflex combinations, which also require persistent treatment either by the principle of direct persistent psychotherapy or with the aid of additional suggestive procedures.

## Reflex flaccid paralyses /378

If we exclude the cases of reflex contracture, there remains a significant group of reflex flaccid paralyses which present particular difficulties for diagnosis as well as for therapy.

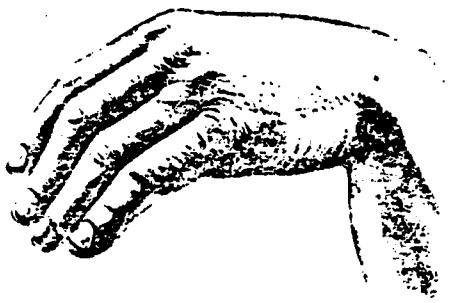

Fig. 147. Reflex paralysis of the hand with wound to the lower third of the forearm injuring the dorsal interosteal nerve.

Here also, as in the reflex contracture, the basis of the syndrome is an injury to the nerve trunk (fig. 147, 148). However, the localization of the injuries here is somewhat different than in the reflex contracture: here the injury of the cutaneous nerves is observed more often.

According to the materials for the development of illness /379 histories, reflex paralysis was noted in 0.1% of all peripheral nerve injuries.

An interesting analysis of reflex paralysis with injuries to the cutaneous nerves was presented by F. M. Lampert. In 8 cases, injury to the internal cutaneous nerve of the crus

Fig. 148. Reflex paralysis of the plantar flexors with injury to the medial cutaneous nerve of the crus in the upper third of the crus.

Fig. 149. Reflex paralysis of the plantar extensors with injury to the lateral cutaneous nerve of the crus.

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and in 1 case, injury to the cutaneous nerve of the back /379
of the foot caused reflex paralysis of the sciatic nerve. In 1 case, injury to the sural nerve caused paralysis of the fibular nerve. In 7 cases, injury to the cutaneous nerves on the brachium, forearm or hand causes paralysis of the radial nerve. In most cases this paralysis occurred immediately after the wound was sustained and was extremely stable. It was often accompanied by a high anesthesia of the amputation stump type and by intensive vegetative-trophic disruptions

disappeared after desympathization. However, the paralysis remained after desympathization. All these forms of paralysis were conditioned by the irritation of the sympathetic fibers, and the over-stimulated sympathetic system has an inhibiting effect on the animal nervous system (L. A. Orbeli, L. V. Tonkikh, K. I. Kunstman). Often under these conditions there was noted a unique clinical variant. The injury of the nerve trunk in its distal region leads to the development of paralysis of this nerve over a considerably greater extent, including the muscle branches which diverge much more proximally of the point of injury. These types of reflex paralysis are quite frequent with injuries to the lower extremities, in which the reflex contracture is observed extremely rarely. An increase in tendinous reflexes may also be observed with these types of flaccid paralysis. N. A. Popov in some cases noted a tonic character of the reflexes. Vegetative-trophic disruptions here are expressed less intensively than in the reflex contracture, and sensitivity disruptions are very similar to those described above. More often diffuse wasting of the musculature is observed.

P. K. Anokhin gave an interesting physiological analysis of these types of paralysis. Paralyses which do not fit into the understandable anatomical scheme in injury to one or another peripheral nerve he termed "central components of trauma to the peripheral nerve". This component is reduced to the loss of various central functions due to the spread of traumatic excitation along the central nervous system. Also possible here are paralyses in the area of a nerve which is completely unafflicted by trauma as well as paralysis of the nerve branches diverging from it much more proximally of the point of injury, and also as well as paralysis of the undamaged part of the nerve trunk with its partial severance. These types of paralysis depend, according

to P. K. Anokhin, either on the fact that the synapses of the neurons in the spinal cord are in a deep inhibited state ("local shock"), or on the fact that they are degenerating, or -- in even more severe cases -- on the fact that the spinal cells themselves are degenerating. P. K. Anokhin considers it incorrect to designate these conditions as reflex paralysis. Analogously (local shock in the system of the tubercle of the thalamus), he also explains those sensitivity disruptions which often enter into the zone directly supplied by the injured nerve. P. K. Anokhin proposes the use of a unique "formula for central loss": C = A - B, where C is the value of the central loss, A is the volume of movement with electrical stimulation, and B is the volume of the same movement with volitional effort.

As one of the measures increasing the excitability of the nerve centers and the nerve fibers and bringing chronaxy to the norm, P. K. Anokhin recommends intra-trunk injections of strychnine (1 $cm^3$ of solution 1 : 1,000).

The role of the animal nervous system in the emergence /380
of this paralysis is clarified by these studies conducted by P. K. Anokhin. The role of the over-stimulated sympathetic reflex arch is considerably smaller. We saw that the severance of this arch, eliminating the contracture, in a number of cases does not eliminate reflex paralysis. Evidently, here "local shock" has spread along the lower motor neuton. All this testifies to the significantly greater complexity of the reflex syndromes which develop under these conditions and which cannot be attributed wholly either to the vegetative nor to the animalistic system. In cases where we encounter a reflex contracture in combination with paralysis, we should thus think of a dual mechanism: of the over-stimulated arch of the sympathetic reflex which influences motor innervation,

and of the simultaneous "local shock" in the zone of the lower motor neuron.

Reflex paralysis, similar to contractures, for the most part is established immediately after the injury is sustained. It differs in its stubborn, prolonged course. However, milder cases have been observed which have undergone spontaneous cure. The differential diagnosis of these types of reflex paralysis from hysteria is particularly difficult.

First of all, the true nature of the syndrome in a number of cases (specifically when the extremity is not diffusely paralyzed) is indicated by the locomotory formula of the paralysis itself. In these cases, it is often easy to see a loss of function of a very definite nerve area in the formula of movement loss. This is not characteristic of psychogenic paralysis. In the latter, regardless of which nerve serves one or another set of movements, the patient suffers paralysis of the arm or hand and fingers, or only the fingers, or only certain fingers. In reflex paralysis, on the other hand, movements are lost which depend on the innervation of a definite nerve trunk.

With a low injury to the median nerve, the patient flexes his fingers as if the nerve had been damaged at a considerably higher level. Evidently, in these cases the entire system of the median nerve is in a state of stable inhibition. Often analogous, anatomically fully understandable dissociations of paralysis may also be observed on the foot and the toes.

Characteristic for true reflex paralysis is the constancy of its motor formula under repeated investigation, while in

hysteria usually subsequent examinations already give a different picture.

Further, reflex paralysis is retained in the phase of excitation at the beginning of ether narcosis. This method is often difficult for precise evaluation, but sometimes it makes it possible to obtain very definite data.

Sometimes in the muscles which are in a state of reflex paralysis it is possible to find a quantitative reduction in electro-excitability -- this also speaks against the psychogenic origin of the paralysis.

Particularly important in this diagnosis is the analysis of nonvolitional or concommitant movements: in the hysteria patient they are retained, while in true reflex paralysis they are lost. For their clarification it is necessary to use special motor tests, sometimes individualized for each patient.

Thus, for example, if we forcefully press together the tips of the I and V fingers, the other fingers (especially the IV) are automatically flexed. If, however, the patient tries not to flex the II-IV fingers during this test, he is able to avoid their flexion by forcefully tensing the extensors. With flaccid paralysis of the II-IV fingers, this test may perform an important service. The II-IV fingers remain /381 immobile, while the study of their passive mobility confirms the fact that their extensors are not tensed. This means that their paralysis is not hysterical, but physiopathic.

Such tests are especially valuable in dissociated reflex paralysis on the lower extremities, since here it is possible to use the automatic regulation of equilibrium in the vertical

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## Reflex flaccid paralyses /378

If we exclude the cases of reflex contracture, there remains a significant group of reflex flaccid paralyses which present particular difficulties for diagnosis as well as for therapy.

Fig. 147. Reflex paralysis of the hand with wound to the lower third of the forearm injuring the dorsal interosteal nerve.

Here also, as in the reflex contracture, the basis of the syndrome is an injury to the nerve trunk (fig. 147, 148). However, the localization of the injuries here is somewhat different than in the reflex contracture: here the injury of the cutaneous nerves is observed more often.

According to the materials for the development of illness /379 histories, reflex paralysis was noted in 0.1% of all peripheral nerve injuries.

An interesting analysis of reflex paralysis with injuries to the cutaneous nerves was presented by F. M. Lampert. In 8 cases, injury to the internal cutaneous nerve of the crus

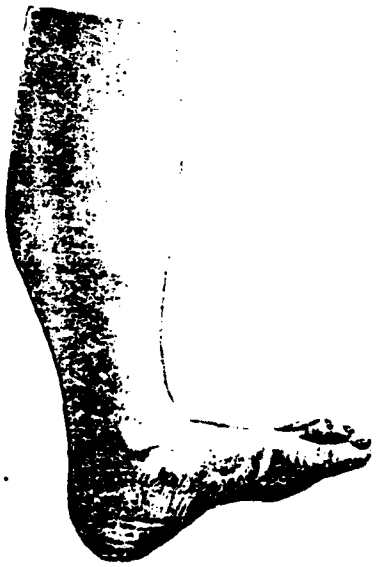

Fig. 148. Reflex paralysis of the plantar flexors with injury to the medial cutaneous nerve of the crus in the upper third of the crus.

Fig. 149. Reflex paralysis of the plantar extensors with injury to the lateral cutaneous nerve of the crus.

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and in 1 case, injury to the cutaneous nerve of the back of the foot caused reflex paralysis of the sciatic nerve. /379
In 1 case, injury to the sural nerve caused paralysis of the fibular nerve. In 7 cases, injury to the cutaneous nerves on the brachium, forearm or hand causes paralysis of the radial nerve. In most cases this paralysis occurred immediately after the wound was sustained and was extremely stable. It was often accompanied by a high anesthesia of the amputation stump type and by intensive vegetative-trophic disruptions

disappeared after desympathization. However, the paralysis remained after desympathization. All these forms of paralysis were conditioned by the irritation of the sympathetic fibers, and the over-stimulated sympathetic system has an inhibiting effect on the animal nervous system (L. A. Orbeli, L. V. Tonkikh, K. I. Kunstman). Often under these conditions there was noted a unique clinical variant. The injury of the nerve trunk in its distal region leads to the development of paralysis of this nerve over a considerably greater extent, including the muscle branches which diverge much more proximally of the point of injury. These types of reflex paralysis are quite frequent with injuries to the lower extremities, in which the reflex contracture is observed extremely rarely. An increase in tendinous reflexes may also be observed with these types of flaccid paralysis. N. A. Popov in some cases noted a tonic character of the reflexes. Vegetative-trophic disruptions here are expressed less intensively than in the reflex contracture, and sensitivity disruptions are very similar to those described above. More often diffuse wasting of the musculature is observed.

P. K. Anokhin gave an interesting physiological analysis of these types of paralysis. Paralyses which do not fit into the understandable anatomical scheme in injury to one or another peripheral nerve he termed "central components of trauma to the peripheral nerve". This component is reduced to the loss of various central functions due to the spread of traumatic excitation along the central nervous system. Also possible here are paralyses in the area of a nerve which is completely unafflicted by trauma as well as paralysis of the nerve branches diverging from it much more proximally of the point of injury, and also as well as paralysis of the undamaged part of the nerve trunk with its partial severance. These types of paralysis depend, according

to P. K. Anokhin, either on the fact that the synapses of the neurons in the spinal cord are in a deep inhibited state ("local shock"), or on the fact that they are degenerating, or -- in even more severe cases -- on the fact that the spinal cells themselves are degenerating. P. K. Anokhin considers it incorrect to designate these conditions as reflex paralysis. Analogously (local shock in the system of the tubercle of the thalamus), he also explains those sensitivity disruptions which often enter into the zone directly supplied by the injured nerve. P. K. Anokhin proposes the use of a unique "formula for central loss": C = A - B, where C is the value of the central loss, A is the volume of movement with electrical stimulation, and B is the volume of the same movement with volitional effort.

As one of the measures increasing the excitability of the nerve centers and the nerve fibers and bringing chronaxy to the norm, P. K. Anokhin recommends intra-trunk injections of strychnine (1 $cm^3$ of solution 1 : 1,000).

The role of the animal nervous system in the emergence /380
of this paralysis is clarified by these studies conducted by P. K. Anokhin. The role of the over-stimulated sympathetic reflex arch is considerably smaller. We saw that the severance of this arch, eliminating the contracture, in a number of cases does not eliminate reflex paralysis. Evidently, here "local shock" has spread along the lower motor neuton. All this testifies to the significantly greater complexity of the reflex syndromes which develop under these conditions and which cannot be attributed wholly either to the vegetative nor to the animalistic system. In cases where we encounter a reflex contracture in combination with paralysis, we should thus think of a dual mechanism: of the over-stimulated arch of the sympathetic reflex which influences motor innervation,

and of the simultaneous "local shock" in the zone of the lower motor neuron.

Reflex paralysis, similar to contractures, for the most part is established immediately after the injury is sustained. It differs in its stubborn, prolonged course. However, milder cases have been observed which have undergone spontaneous cure. The differential diagnosis of these types of reflex paralysis from hysteria is particularly difficult.

First of all, the true nature of the syndrome in a number of cases (specifically when the extremity is not diffusely paralyzed) is indicated by the locomotory formula of the paralysis itself. In these cases, it is often easy to see a loss of function of a very definite nerve area in the formula of movement loss. This is not characteristic of psychogenic paralysis. In the latter, regardless of which nerve serves one or another set of movements, the patient suffers paralysis of the arm or hand and fingers, or only the fingers, or only certain fingers. In reflex paralysis, on the other hand, movements are lost which depend on the innervation of a definite nerve trunk.

With a low injury to the median nerve, the patient flexes his fingers as if the nerve had been damaged at a considerably higher level. Evidently, in these cases the entire system of the median nerve is in a state of stable inhibition. Often analogous, anatomically fully understandable dissociations of paralysis may also be observed on the foot and the toes.

Characteristic for true reflex paralysis is the constancy of its motor formula under repeated investigation, while in

hysteria usually subsequent examinations already give a different picture.

Further, reflex paralysis is retained in the phase of excitation at the beginning of ether narcosis. This method is often difficult for precise evaluation, but sometimes it makes it possible to obtain very definite data.

Sometimes in the muscles which are in a state of reflex paralysis it is possible to find a quantitative reduction in electro-excitability -- this also speaks against the psychogenic origin of the paralysis.

Particularly important in this diagnosis is the analysis of nonvolitional or concommitant movements: in the hysteria patient they are retained, while in true reflex paralysis they are lost. For their clarification it is necessary to use special motor tests, sometimes individualized for each patient.

Thus, for example, if we forcefully press together the tips of the I and V fingers, the other fingers (especially the IV) are automatically flexed. If, however, the patient tries not to flex the II-IV fingers during this test, he is able to avoid their flexion by forcefully tensing the extensors. With flaccid paralysis of the II-IV fingers, this test may perform an important service. The II-IV fingers remain /381 immobile, while the study of their passive mobility confirms the fact that their extensors are not tensed. This means that their paralysis is not hysterical, but physiopathic.

Such tests are especially valuable in dissociated reflex paralysis on the lower extremities, since here it is possible to use the automatic regulation of equilibrium in the vertical

position, particularly on one leg. If the patient is able to perform active abduction of the foot, but cannot perform its extension -- this is still not proof of the actuality of paralysis. However, when the same patient retains his equilibrium while standing on the injured leg, and the contraction of the fibular musculature is evident while the extensors of the foot remain flaccin, which cannot be done on purpose and consequently even hysteria cannot create this symptom, this means that true reflex paralysis is present. Just as characteristic is the non-volitional contraction of the extensors of the foot (the clearly visible tendons of the anterior tibial muscle are tensed) while the body of the vertically standing patient is tilted backward. This postural reflex is distinguished by a great constancy, and its absence is typical for reflex paralysis.

With the aid of a number of methods, it is also possible answer the question of whether we are dealing with hysterical or reflex paralysis. Thus, the patient with flaccid paresis of some muscle group (for example, the digital flexors) tries to perform this movement, but completes it in a very small volume. If at that moment we were to slightly nudge the paretic segment (for example, slightly press on the dorsal surface of the fingers), in hysterical paralysis this is often met with the tension of the antagonists (in this example -- the digital extensors), with the aid of which the patient graduates the limited volume of the given movement. In reflex paralysis, the antagonists remain flaccid under these conditions. S. V. Gol'man has recently proposed several other tests for distinguishing hysterical paralysis (which he identifies with reflex) from real paralysis. Thus, if in a patient with flaccid paralysis of the fingers we perform passive flexion - extension of the finger while at the same time distracting

the attention of the patient with some other complex tasks, and then suddenly we release this finger, with hysterical paralysis the finger is retained in the position given to it.

If in the course of a number of cases we have gradually learned to diagnose reflex paralysis more assuredly, in regard to therapy the matter is somewhat worse. Operations on the damaged nerves (neurotomy of the cutaneous nerves, removal of the neuroma, excision of painful scars, neurolysis operation, etc.) sometimes have a rather quick favorable effect, as does energetic physio- and mechanotherapy. E. A. Asratyan notes good results with the prolonged application of soporifics which cause 12-13 hrs. of sleep.

However, there remain stubborn cases in which it was finally necessary to direct the uncured patients to the Military Physician's Commission.

An analysis of the manifestations of reflex paralysis has made it possible to isolate two more motor syndromes in which the loss does not correspond to the innervational zones of the specific nerves. These are anthalgic paralysis or paresis and concommitant paralysis.

The syndrome of anthalgic (anti-pain) paralysis is not usually specifically isolated, while the anthalgic contracture is well known. The latter depends on the prolonged volitional placement which finally may lead to muscle retraction. /382
Anthalgic paralysis is another manner. Here active movements become impossible, since they cause pain. The anthalgic contracture in this case is not at all mandatory. These types of paralysis often cause diagnostic error. Thus, the patient is unable to extend the hand, since it turns out that there is a painful neuroma on the median nerve which causes irradiating pain upon tension. To a certain degree these types of paralysis

also may be called "reflex". However, in principle they differ significantly from the preceding group of cases where passive movements by the paralyzed segments may be completely painless. The therapy of these types of paralysis is fully understandable: here it is first of all necessary to eliminate the pain from the passive movement, after which physio- and mechanotherapy comes into its own.

The subsequent fate of these types of anthalgic paralysis is unique. In some cases they gradually disappear parallel with the elimination of pain in the corresponding movements. In other cases the pain disappears with passive movements while the paralysis remains. Here the muscle is paralyzed not because its contraction is painful, but because it was painful at one time. Thus there often arises paralysis of all the movements of the foot or hand with paradoxally retained movements of the digits in those cases when, as a result of injury, movement in the radiocarpal or talocrural joints was at one time painful, while the patient was able to move the digits from the outset. This type of paralysis is evidently closest to psychogenic. Not being hysterical in the direct sense, it nevertheless depends evidently on the fixed placement, and energetic psycho- and physiotherapy are required in order to remedy this defect. L. G. Fidel'gol'ts spoke of "functional apraxy" or "the gradual diminuation of themovement formulas". In the next few days after the injury is sustained, paralysis of this type disappears very rapidly if its origins are explained to the patient.

Concommitant or combined paralysis presents a phenomenon of a different nature. This is the inability to actively contract some muscle group which has fully retained its neural connections only because the function of their habitual

synergists has been lost and the patient has not yet learned to use these muscle groups under the conditions of new and unfamiliar motility. These syndromes are quite varied. They may complicate not only paralysis in nerve trunk injuries, but also the loss of certain movements due to tendon injuries. They are especially demonstrative in the latter case. These syndromes are rather individual and evidently depend to a large degree also on the level of prior motor training. Sometimes it was possible to observe how after a tendon operation, when the basic lost movement was being restored, concommitantly lose movements also began to appear. This syndrome is undoubtedly encountered more frequently than it is recognized. If we force such a patient to perform various isolated movements with his healthy extremity, it is easy to see that he has rather non-differentiated motility. Evidently, the presence of the concommitant paralysis syndrome is noted more often in people with such poor motility. Of course, the role of exercise and physical therapy in liquidating complications of this type is understandable.

The entire sphere of reflex or reflected disorders in firearms injuries to the peripheral nerves has thus turned out to be, according to the experience of the Great Patriotic /383 War, considerably more complex than was first believed. At the same time, much in this area has now become so clear that it could be applied successfully in the selection of proper treatment. Soviet neuropathologists and neurosurgeons who have given so much attention to this unfinished and confused chapter of neuropathology may truly feel a certain satisfaction from the results of their work.

## Surgical treatment of reflex contractures

"There is not a single part of the body in which firearms injuries are so infinitely varied by type, degree, complications and consequences as in the arm and the lower part of the forearm" (N. I. Pirogov).

Among these injuries, the most unique are reflex contractures, which most often develop after firearms injuries to the region of the radiocarpal articulation, the lower third of the forearm and the hand. According to the materials for the development of illness histories, reflex contractures and paralyses were noted in 0.5% of all cases of firearms injuries to the nerve trunks. They usually arose at the moment of injury and continued on a clear background of vegetative and trophic disorders. It was by far not always possible to establish the injuries to the nerve trunks, cutaneous nerves and their branches. Often during the surgical operation only injury to the bones, ligament apparatus, muscle tendons at attachment points, cicatrical foci in the aponeurosis, and finally the presence of a foreign body or multiple impregnation of soft tissues with powder could be established.

Reflex contractures, reflex paralyses, causalgia -- these clinical syndromes which are not motivated by an anatomical substrate -- have a similar anatomo-functional mechanism, specifically the damage to endings of the sympathetic nervous system, the disruption of its effector, i.e., vasomotor and secretory functions, and the disruption of its adaptation-trophic activity. In a number of cases, as P. K. Anokhin believes, under the influence of defective impulses coming from the periphery, there arises a disruption of the stimulation-inhibition processes in the central

apparata of the nervous system. This in some cases is expressed by the development of a reflex contracture, and in others -- reflex paralysis. "Here in some cases among the phenomena developing in the zones which are not innervated by the damaged nerves there is a predominance of disruption in the functions of the motor apparatus, in other cases -- a disruption of the functions of the sensory apparatus, and in still others -- a disruption in the function of the visceral-effector apparatus. These various forms of remote reactions to trauma were described by various authors as different illness forms, as individual nosological units. Nevertheless, in all such cases we are dealing with the same nosological unit, which is distinguished by great polymorphism but has a single pathogenesis and therefore the same therapy" (A. M. Grinshteyn).

Operative intervention must be performed, if we may say so, by level and by stage. The first stage is the operation performed at the point of injury. It has the complex and sometimes technically difficult task of eliminating the focus of irritation: removing fragments from the body of ligaments, muscles and tendons; excising scar formations, sometimes impregnated with gunpowder; freeing thin nerve trunk branches from the scars, particularly branches of the dorsal interosteal nerve, performing neurolysis of larger nerve branches, etc. In individual cases these interventions /384 require precise anatomical orientation and fine operative technique. These operations should be performed as soon as possible after healing of the wound before faulty reflexes have developed and the manifestations of ascending neuritis have not yet become widespread. A. Yu. Sozon-Yaroshevich, S. Yu. Minkin, V. Ya. Rabkin, N. A. Popov and others, adhering to this methodology, obtained successful results along with the presence of unfavorable outcomes. In 38 such operations,

A. Yu. Sozon-Yaroshevich obtained improvement in only 13 patients, 6 of whom showed a restoration of combat fitness and work capacity. V. Ya. Rabkin obtained improvement in all 3 of his cases, although restoration of combat fitness was not observed. In 2 cases of reflex contracture, F. M. Golub obtained significant improvement; in one case the "dorsal interosteal nerve of the forearm was thoroughly separated out along the entire extent of the interosteal ligament to its fine branchings; it was cicatrically fused over a considerable extent". In another case, a metal fragment 0.5 x 0.2 cm in size was removed from scars which were fused with the superficial branch of the radial nerve. Improvement was already noted on the operating table, and subsequently progressed.

Thus, operations performed on the point of firearms injury may by means of eliminating the focus of irritation free the central apparata from stimulation or over-stimulation, i.e., inhibition.

The second stage of the operation is neurotomy of the cutaneous nerves above the focus of injury. A. G. Molotkov ascribes a particular role to injuries of the cutaneous nerves in the development of the reflex contracture. In particular, he considered them to be conductors of stimulating impulses from the center of irritation. The same viewpoint was also shared by N. A. Popov and V. L. Lesnitskaya. L. A. Orbeli, V. N. Shevkunenko, F. M. Lampert and others believe that the cutaneous nerve are sensitive in the same degree as the vegetative due to the considerable content of sympathetic fibers within them. Particularly characteristic in this respect are injuries to the cutaneous nerve of the forearm and even more so injuries to the branch of the dorsal interosteal nerve of the forearm. The observations

of numerous surgeons testify to the large role which the cutaneous nerves of the forearm and crus play in the development of the reflex and vegetative-trophic syndromes. They are also conductors for deep innervation fascicles, which have a great significance in the genesis of the reflex contracture.

The intersection of the cutaneous nerves above the focus of the injury was performed by numerous authors (V. L. Lesnitskaya, A. G. Molotkov, N. A. Popov, A. Yu. Sozon-Yaroshevich and others). However, the results were variegated and it was not always possible to establish which nerve is subject to intersection. This is why the circular block according to Vishnevskiy, repeatedly performed, may sometimes give a positive result. The exclusion of the cutaneous nerves is thus more fully implemented. The alcoholization of these nerves cannot be recommended. V. N. Shamov rightfully indicates the possibility of scar formations which might be the reason for new defective reflexes. Moreover, alcohol inflict "gross chemical trauma" upon the nerve tissue (A. D. Speranskiy).

The combination of the described neurotomies with desympathization of the arterial vessels corresponding to the localization of the scar is more rational. According to the materials for the development of illness histories, desympathization was performed in 0.18% of all operative interventions on the peripheral nervous system in connection with firearms injuries.

Periarterial desympathization is also an important /385
addition to the intervention on the primary focus. However, it should be noted that the low effectiveness of this inter-

vention often depends on the technical inadequacy in implementing this operation. Desympathization of the artery must be performed by a single graft, and not by the method of piecing and pinching. Moreover, desympathization must be done on an extensive section of the artery, approximately over an extent of 12-15 cm. Only under such conditions is it possible to obtain appropriate segmental exclusion of the vegetative innervation of the extremity.

These are the interventions of the first stage.

If all the described measures are insufficient and ineffective, the question arises of intervention at a higher level -- at the marginal trunk, i.e., the question of cervical-thoracic or upper thoracic gangliectomy in cases of reflex contracture of the hand, and of lumbar gangliectomy -- in traumatic injuries to the foot and crus. A novocaine block of the appropriate sympathetic ganglia is first performed. Access to the stellate ganglion and the upper thoracic ganglia is gained on the side of the neck and on the side of the back. Block of the lumbar ganglia is performed easily from the back. For the injection it is most expedient to use 1-2% novocaine solution in amounts of up to 30 $cm^3$. The positive effect of the block in the form of disappearance of the contracture of the hand or foot is usually short-lived, but it does testify to the expediency of gangliectomy. Sometimes the block gives a more lasting effect -- up to 2 hours. Then the question arises of the possibility of using it as an independent method of treatment. In these cases, repeated blocks with subsequent physiotherapy, mud therapy and exercise leads to cure or improvement.

Table 38

The results of surgical treatment of reflex contractures according to the materials of A. Yu. Sozon-Yaroshevich

| | Total effect | Partial effect | No result | Total |
|---|---|---|---|---|
| Revision in area of injury | 6 | 7 | 25+3 in combination with sympathectomy | 41 |
| Desympathization of the artery..... | 1 | 1 | - | 2 |
| Revision in the area of injury and operation on the vessels..... | 2 | 7 | 16 | 25 |
| Sympathectomy of the second and third thoracic ganglion..... | 4 | - | - | 4 |
| Block of sympathetic ganglia..... | 1 | 3 | - | 4 |
| Total... | 14 | 18 | 44 | 76 |

Operative intervention on the marginal trunk may be preganglionar and postganglionar. If we are speaking of change in the effector vasomotor and secretory functions, then a preganglionar sympathectomy is substantiated and expedient. After this intervention, no increased sensitivity is noted in the performing organs to the active physiological substances circulating in the blood. In the case of reflex /386 contracture, the purpose of operative intervention is the severance of those paths along which unusual, defective and distorted impulses pass to the periphery. Under these conditions, the preganglionar, ganglionar, and postganglionar sympathectomy are all equally effective. Most Soviet surgeons used the method of the preganglionar sympathectomy in reflex

contractures. However, the number of such cases is insignificant (A. N. Bakulev - 5, B. G. Yegorov -- 11, F. M. Lampert - 2, S. Yu. Minkin - 5, A. Yu. Sozon-Yaroshevich - 4). The most extensive material on the surgical treatment of reflex contractures belongs to A. Yu. Sozon-Yaroshevich (table 38).

Gangliectomy gives the best effect and may be considered expedient and necessary in all cases when interventions of the first stage at the point of injury and in the form of removal of the focus of irritation or operation on the cutaneous nerves and on the peripheral vessels (desympathization) do not give improvement.

## CHAPTER VII

## CAUSALGIA AND ITS TREATMENT

### The anatomo-topographical specifics of the vegetative nervous system

Despite the fact that anatomical manuals describe the spinal and vegetative nervous systems separately, nevertheless in essence these two systems, which at first glance appear to be separate -- are indeed one.

The vegetative system is anatomically and physiologically tied with the spinal and, consequently, its functions are in a strict dependence on the function of the cortex of the large hemispheres.

This is why the name "autonomous nervous system" does not reflect its physiological role in the life activity of the organism.

The concept of the vegetative nervous system as being "autonomous", whose function is independent of the function of the central nervous system, contradicts the essence of Pavlov's teaching.

The united session of the USSR Academy of Sciences and the USSR Academy of Medical Sciences, which was devoted to the studies of I. P. Pavlov, demonstrated the leading role of the central nervous system in the life activity of the organism, and also exposed erroneous concepts on the vegetative nervous system, whose activity is supposedly not connected with the activity of the cortex of the large hemispheres.

Examining the vegetative nervous system as an organic component part of the single nervous system with its central organ -- the large hemispheres, injuries to the spinal nerves should be interpreted as injuries to the spinal and vegetative system, since every spinal nerve contains sympathetic and parasympathetic elements.

The experience of the war has shown that in different persons the clinical picture of injury to identical spinal nerves at the same level is in most cases non-uniform. The differences concerned not only the area of sensitivity disruption, its aspects, paralyses of the individual muscles and their groups, but also vascular, pilomotor, trophic and other disorders.

The latter circumstance testifies to the fact that injury to any spinal nerve must be viewed also as injury to the fibers of the vegetative nervous system.

There is not a single spinal nerve which does not contain a greater or lesser amount of fibers and conductors of the sympathetic and parasympathetic system.

It is by far impossible to draw a distinct anatomical boundary between the vegetative and spinal system, particularly if we speak of the peripheral regions.

The latter circumstance has an important significance /388 in understanding and interpreting a number of clinical phenomena observed in injury to the peripheral spinal nerves, as well as injury to the vessels and the extremity as a whole.

It is natural to assume that the non-uniform distribution of vegetative elements in the peripheral sections of the spinal nervous system inevitable is expressed in the differences of trophic disorders and pain syndromes which are so multiply presented in the clinical descriptions of firearms injuries to the spinal nerves.

The vegetative nervous system includes two distinct systems -- the parasympathetic and the sympathetic. This has greater theoretical significance, since in practice, using modern methods of morphological study, it is impossible to clearly delineate these regions at the periphery.

Nevertheless, surgical intervention still requires some sort of initial data through the use of which it would be possible to a greater or lesser degree of certainty to distinguish these systems in the zone of operation and thereby to give greater precision to the intervention being undertaken.

The central and peripheral region of the vegetative nervous system are distinguished.

The central region of the parasympathetic system in turn consists of two basic regions -- the cranial and the sacral.

The cranial region includes the nuclei of the mid-cerebral part, from which the parasympathetic elements come (within the composition of the oculomotor nerve), and a bulbar part, from whose nuclei the fibers go within the composition of the facial, glossopharyngeal and vagus nerve.

The sacral region consists of a collection of cells found in the sacral part of the spinal cord within the limits

of the second-third sacral segments, from which the fibers forming the pelvic nerves originate.

Related to the peripheral regions of the parasympathetic system is the vagus nerve and its derivatives, as well as the pelvic nerves, whose number varies. The pelvic nerves participate in the formation of the hypogastric plexus and the plexuses of organs of the small pelvis, within the limits of which it is impossible to morphologically distinguish the parasympathetic and sympathetic elements.

The central regions of the sympathetic systems are the collection of nerve cells located along the spinal cord from the eighth cervical to the second-fourth lumbar segment within the limits of the lateral cornua. Aside from the listed central regions, the vegetative centers are included in the subcortical ganglia of the diencephalon, the cerebellum, etc.

The specifics of the structure of the vegetative system reflect the complexity of its genesis in man.

At the present time, most authors adhere to the neuron theory of the structure of the vegetative nervous system (V. A. Dogel', A. A. Zavarzin, B. I. Lavrent'yev), and not the syncytial, where the individuality of the neuron and its axon is lost. The data of embryology and comparative anatomy show that the process of formation of the vegetative nervous system takes place primarily along the path of morphological differentiation of the sympathetic and parasympathetic system.

In the process of forming the peripheral regions of the sympathetic nervous system there is a migration of neuro-

blasts from the center (spinal cord) to the periphery. Part /389
of them participate in the formation of the future marginal trunk and form its ganglia (vertebral region); often however, by-passing the marginal trunk, it is concentrated on the periphery, forming the ganglia of the solar, aortal and other plexuses (prevertebral region).

The migration process is not always monotypic: part of the cells seem to fall short of their final territories (plexuses) and stop at the medial branches connecting the marginal trunk with the plexuses of the prevertebral region of the sympathetic nervous system, as well as on the lateral connective branches which connect the spinal and sympathetic system into a single whole.

Of the two presented schemes (fig. 150 and 151) it is evident that in different persons the location of the gangliose cells of the sympathetic nervous system is different, and morphologically the system itself has external differences which are easily determined on the operating table.

Studies show (V. N. Shevkunenko) that in a number of cases the vagus nerve and its branches have a very small number of connections with the branches of the sympathetic ganglia. On the contrary, in other cases often the branches of the vagus and sympathetic nerve are not only joined together, but even merge into a single formation. For example, the ganglion of the vagus nerve is closely connected into a single entity with the superior cervical ganglion of the sympathetic nerve.

N. S. Sevbo showed that in such cases in the ganglia of the sympathetic nerves it is possible to find cells which are characteristic for the parasympathetic system and, on the

other hand, in the composition of the parasympathetic system there are cells from the sympathetic system. The data of morphological studies speak of the fact that with a large number of connections between the branches of both systems at the point of connection of individual nerves there are noted accumulations of gangliose cells -- "nodules", which may be of various sizes.

The connections of the type described are observed between the nerve branches of the chest (the pulmonary and cardiac plexus), as well as in the plexuses innervating the organs of the pelvis.

An exceptionally great influence on the process of marginal trunk formation is exerted by the development of the extremities, which is associated with the radical transformation of the primary segments. The latter is externally manifested in the fact that within the limits of segments of the spinal cord corresponding to the level of formation of the extremities, the gangliose masses of the marginal trunk are distributed extremely differently, and in such regions as the chest, where the primary segmentation is more clearly defined as compared with other areas, the number of marginal trunk ganglia corresponds to a greater or lesser degree to the number of segmentally running intercostal nerves.

In the cervical, lumbar, as well as in the sacral region, where the primary segmentation in the body structure has undergone certain transformations, the segmental structure of the marginal trunk is also invariably disrupted, which is expressed in the fusion of the individual ganglia and in the reduction of their overall number as compared with the number of segments subject to transformation in the process of genesis of the given area of the body (formation of the lower extremities).

The differences in the structure of the marginal trunk are basically reduced to the following:

a) In connection with the fact that the process of formation of the nervous system is individual in different persons, the number of ganglia in the marginal trunk may be different. In a number of people the number of ganglia /390 corresponds to the number of segments; in such cases each spinal nerve receives vegetative elements segmentally. With a concentration of ganglionic masses, with fusion of the ganglia and reduction in their number, several spinal nerves receive vegetative elements from a single ganglion.

b) With the dispersion of ganglionic masses, which is observed in the segmental structure of the marginal trunk, its lateral branches -- the connecting branches -- may be numerous and over their extent may have inclusions of nerve cells in the form of individual nodules ("cells, which have not reached" their territories).

The studies of A. A. Burkanova, D. N. Lubotskiy, G. A. Orlov, T. A. Strukgof and others showed that rami communicantes often also contain ganglionic inclusions.

Thus, in the peripheral segment of the sympathetic nervous system it is necessary to distinguish: a) the vertebral section, to which the marginal trunks of the sympathetic nerves are related, its lateral branches (rami communicantes), the sympathetic fibers of the peripheral nerves and the medial branches connecting the marginal trunk with the prevertebral section, and b) the prevertebral section, which includes all the collections of ganglionic cells found primarily in the plexuses located along the course of the aorta and its main branches and being the centers of visceral innervation.

Thus, the marginal trunk of the sympathetic nerve has two types of branches (connections) -- lateral and medial. Among the lateral branches (connections) are the connective branches (rami communicantes), by which the granglia of the marginal trunk are connected with the spinal nerves. The medial branches (connections) join the marginal trunk with the prevertebral plexuses of the nervous system -- the celiac nerves and others. The medial connections, as well as the prevertebral section are not described here, since they have little relation to injuries of the peripheral nerves.

From the standpoint of peripheral nerve injuries, the primary practical significance belongs to the connections of the marginal trunk with the spinal nerves -- the connective branches.

The number of ganglia in the certival section of the marginal trunk is subject to great fluctuation. In a number of cases, six ganglia of various size are noted, and the upper one, as a rule, is larger than the rest and reaches a length of 4-8 cm. The ganglia are primarily located in the lower third of the cervical marginal trunk. In such cases, the central cervical ganglion is usually well expressed in the region of the lower thyroid artery.

In the region of the vertebral artery, behind the subclavian, there may be several ganglia, among which the lower ganglion, which exists independently, i.e., is not connected into a single whole with the first and second thoracic ganglion, is usually more or less clearly expressed. The stellate ganglion, which is a fusion of the inferior cervical and one or two superior thoracic, is absent in these cases (fig. 152). This, structure, according to the data of S. I. Yelizarovskiy, is observed in approximately 28.0% of the cases. In the remaining 72%, the stellate ganglion was clearly apparent.

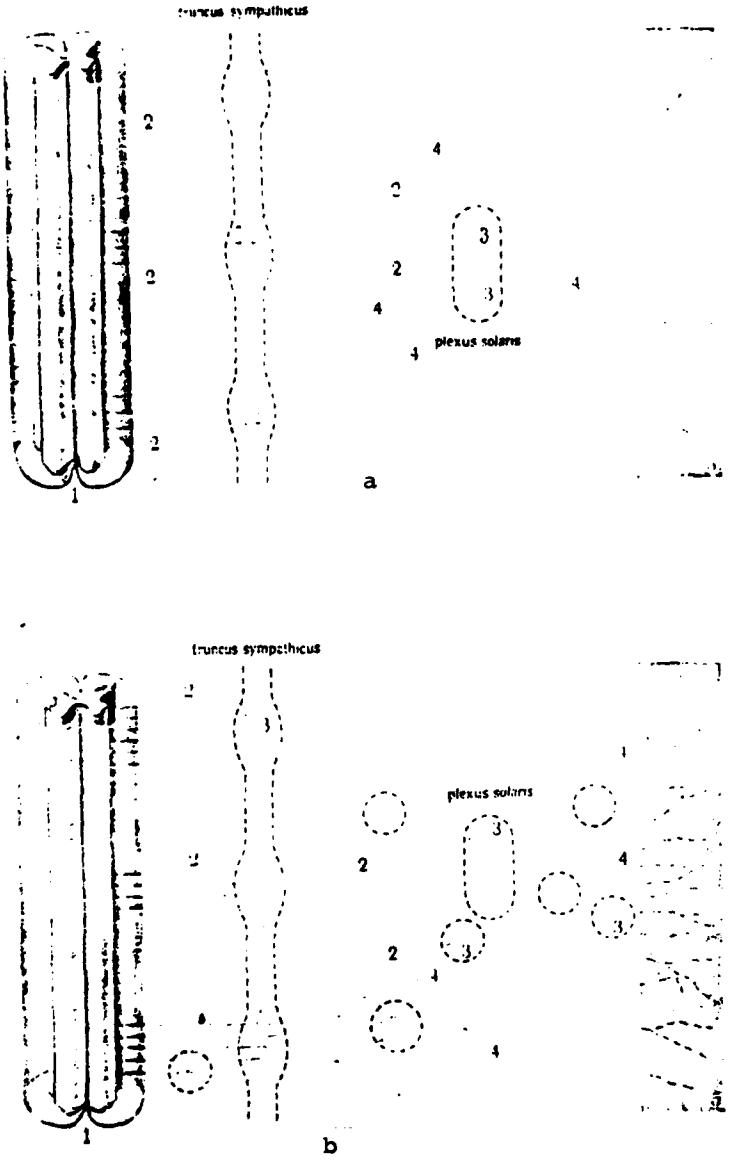



Fig. 150. Scheme of the location of the peripheral neuron of the sympathetic nervous system.

a - with concentration of the ganglionic masses; b - with their dispersity. 1 - spinal cord; 2 - preganglionar fibers; 3 - peripheral neuron; 4 - postganglionar fibers; 5 - internal organs. The sympathetic trunk, solar plexus and additional nodules are traced with a dotted line.

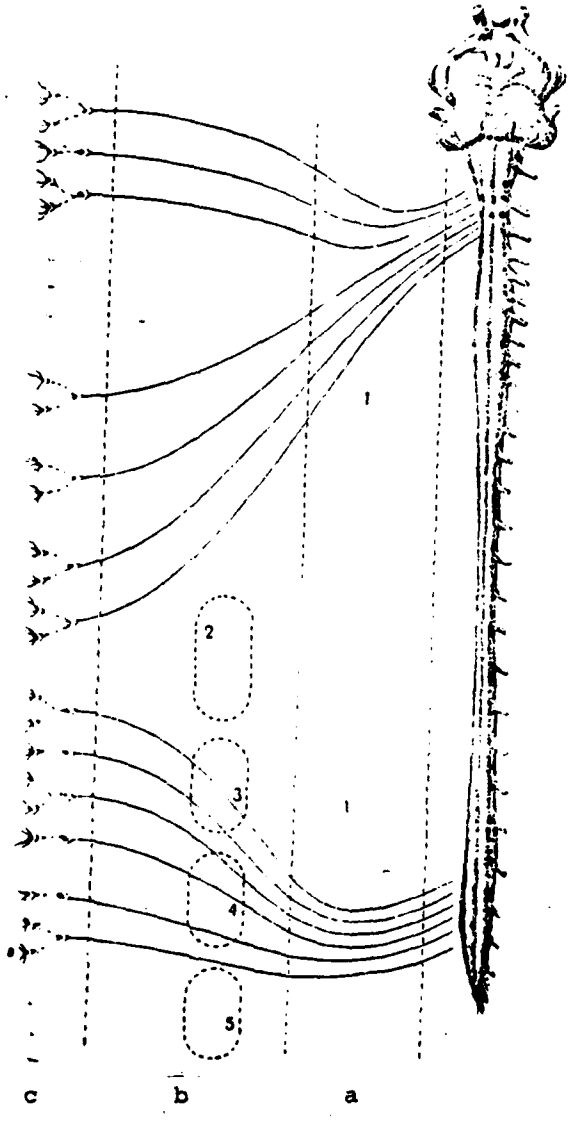



Fig. 151. Scheme of the structure of the vegetative nervous system.

1 - vertebral section; b - prevertebral section; c - territories of innervation. 1 - sympathetic trunk; 2 - solar plexus; 3 - superior mesenteric plexus; 4 - inferior mesenteric plexus; 5 - hypogastric plexus. The solid lines denote the preganglionic fibers, the dotted line -- postganglionic.

With the presence of six ganglia in the cervical section of the sympathetic nerve, i.e., with its segmental structure, a large number of connections of medial branches with the vagus nerve are noted, as well as an accumulation of ganglionic cells on the individual medial branches. The lateral branches differ in the respect that the individual nodules of the sympathetic trunk are connected with individual fascicles /391 of the brachial plexus, and the connecting branches in the area of the fifth-eighth cervical and first thoracic segment contain over their extent extremely insignificant accumulations of nerve cells in the form of nodules of various sizes.

Even in those cases when over the extent of the cervical section of the sympathetic nerve there is a large number of ganglia (segmental structure), the superior cervical ganglion remains large and may reach 10 cm (Baraboshkin). The connecting branches which diverge from its external surface are joined with the spinal nerves of the first-third cervical segment. The number of connections here may vary. Sometimes it is possible to observe individual connecting branches which lead to individual fascicles of the cervical plexus, sometimes several connecting branches are joined with one fascicle or with connections formed between the fascicles which form the cervical plexus.

As shown by the studies of A. Yu. Sozon-Yaroshevich, S. I. Yelizarovskiy, N. S. Korotkevich and others, the superior connective branches are thin and cannot always be found. Their number varies. With the segmental structure /392 of the sympathetic trunk in the area of the neck it is possible to see one or several (up to 6) additional trunks, with ganglionic inclusions being noted along the extent of each of these (P. V. Sinakevich). In those cases when segmentation in the structure of the sympathetic trunk is absent, a

concentration of ganglia from the cervical section of the sympathetic nerve is noted up to the formation of only two ganglia -- the superior cervical and the inferior cervical. The inferior, as we have already said, is usually connected with the superior and sometimes with the second superior thoracic ganglion (the stellate ganglion), forming a single entity.

/391

Fig. 152. The segmental structure of the sympathetic trunk in the cervical region (dispersion of ganglionic masses).

1 - superior ganglion; 2 - middle ganglion; 3 - inferior thyroid artery; 4 - collection of nerve cells on the connective branches; 5 - parallel trunk; 6 - connections with fascicles of the brachial plexus; 7 - cervical plexus; 8 - brachial plexus; 9 - anterior scalene muscle; 10 - vagus nerve; 11 - connections between the vagus nerve and the sympathetic nerve; 12 - cardiac nerves.

With a concentration of ganglionic masses, as a rule, /392 a large number of connections between the medial branches of the cervical sympathetic trunk and the branches of the vagus nerve is not observed.

The fusion of the inferior cervical ganglion with the superior thoracic, i.e., the formation of the stellate ganglion, is observed, according to the data of S. I. Yelizarovskiy, in 72.0% of the cases. The stellate ganglion varies in form: sometimes it is extended lengthwise in a fusiform fashion, sometimes it consists of two closely adjoining ganglia which seem to form the figure eight, sometimes it is a compact mass of circular shape with clearly expressed branches diverging from it. Topographically, the stellate ganglion lies at the level of the transverse process of the VII cervical vertebra and the head of the I rib. The ganglion is usually obliquely placed: its upper pole is turned toward the inside and its lower -- to the outside. As a rule, the stellate ganglion is found behind the vertebral artery. Downward and forward it is slightly covered by the cupola of the pleura and the subclavian artery (fig. 153).

It must be particularly noted that in those cases when the stellate ganglion is shortened and compacted from its circular form, the connective branches which diverge from its outside surface are very long, particularly those which connect the upper fascicles of the brachial plexus (the fourth cervical root and below). This is not observed with the segmental structure of the sympathetic trunk and, consequently, in the presence of a middle cervical ganglion.

In the latter cases, as a rule, the connective branches are short, since they pass at the level of their own segments.

In the thoracic section, as was noted above, the primary segmentation is most often retained. But even here it is often possible to see that the number of ganglia forming the sympathetic trunk may sometimes be reduced to 8, while in other cases their number is equal to 12, and sometimes even 13 (N. A. Burkanova, G. A. Orlov and others).

With the reduction in the number of ganglia, the connective branches join several intercostal nerves with one ganglion of the sympathetic trunk, while with the retention of segmentation, the individual intercostal nerves are each tied with one ganglion, and sometimes -- with several ganglia (N. A. Burkanova). With the retention of segmentation, the connective branches contain an accumulation of ganglionic cells in the form of additional nodules, which are located most often near the intervertebral ganglia (fig. 154).

The number of medial connections also varies. If the number of ganglia does not correspond to the number of segments, then the number of branches forming the celiac nerves may also be correspondingly reduced. However, with the presence of a large number of ganglia, the number of median branches (connections) is also increased.

Without touching upon the other medial branches which participate in the formation of plexuses of the organs in the thoracic and abdominal cavity and which are unrelated to the present topic, it is necessary nevertheless to pause /393 at the levels of formation of the celiac nerves. In some cases the upper margin of formation of these nerves if the fourth thoracic root, while in other cases the superior branches of the major celiac nerve emanate from the third thoracic root. The latter circumstance has an important practical significance in regard to the irradiation of pains

arising in pathological conditions of the organs of the abdominal cavity and in operations on the superior ganglia of the thoracic segment of the sympathetic trunk.

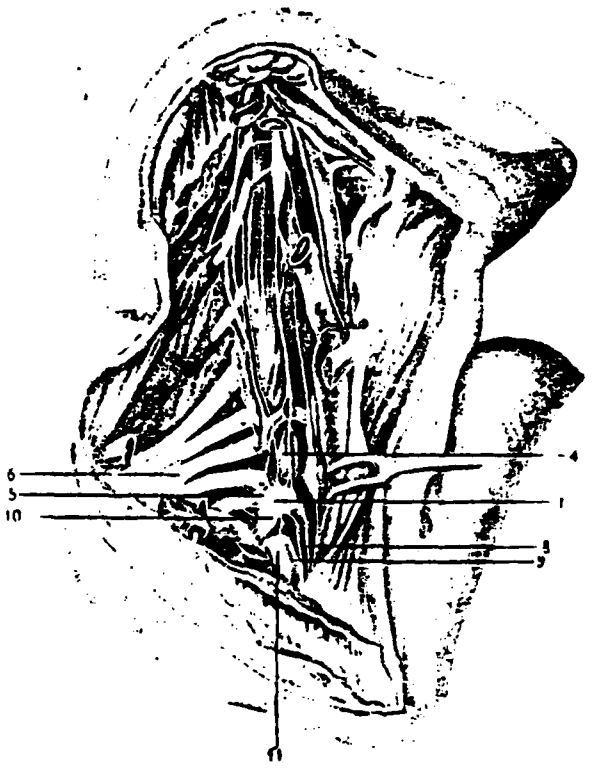



Fig. 153. Structure of the sympathetic trunk in the cervical region with concentration of ganglionic masses.

1 - stellate ganglion; 2 - superior cervical ganglion; 3 - branches connecting the stellate ganglion and the brachial plexus; 4 - brachial plexus; 5 - inferior thyroid artery; 6 - cardiac branches.

The same regularities are noted in the structure of the lumbar region of the sympathetic trunk, specifically: with a sharply expressed concentration of ganglionic masses it is possible to have a reduction in the number of ganglia up to

the point that only one long (5-6 cm) ganglion is formed which is located in the area of the III and IV lumbar vertebra (fig. 155). Numerous connective branches diverge from the external periphery of the ganglion, leading to all the spinal nerves arising from the lumbar plexus. Also diverging from this ganglion are a small number of medial nerves which participate in the formation of the aortal, renal, and other /394 parts of the prevertebral segment of the sympathetic nervous system. If the segmentation of the sympathetic trunk in the lumbar region is retained, there are fusiform elongated ganglia in the area of each vertebra, with short connective branches diverging from them and leading to the corresponding spinal nerves. With the segmented structure, individual accumulations of ganglionic cells may be seen on the connective branches, primarily located, as in the thoracic region, closer to the intervertebral ganglia (fig. 156).

In the sacral region of the sympathetic trunk, the number of ganglia may reach eight, but is sometimes limited to four, and asymmetry is often observed. In comparison with the other sections, in the sacral and in the lumbar regions more often than in the others it is possible to see "intersecting" fibers, connecting ganglia of opposite sides, which predetermines the intersecting vegetative innervation of the lower extremities. The greater the number of ganglia, the smaller they are, and naturally, the shorter their connective branches. However, with a reduction in the number of ganglia there is noted an elongation in the connecting branches. The individual fascicles forming the sciatic nerve are joined by several connective branches with one ganglion. With both types of structure of the sacral region of the sympathetic system there is one coccygeal ganglion connected by branches with the ganglia of the right and left side.

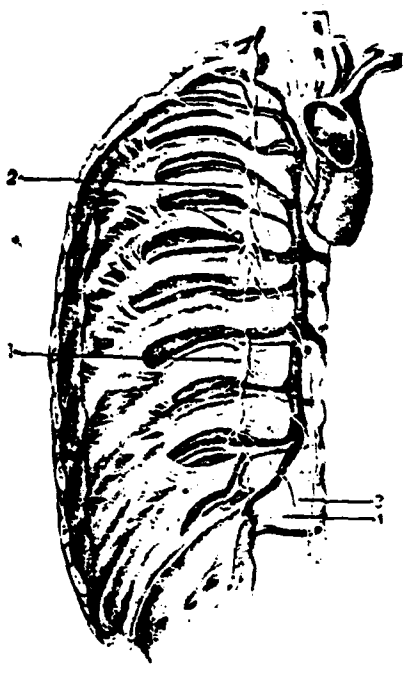



Fig. 154. Structure of the connections between the sympathetic trunk and the spinal nerves in the thoracic section with dispersion of the ganglionic masses.

1 - sympathetic trunk; 2 - ganglionic inclusions along the course of the connective branches.

The described specifics in the structure of the sympathetic trunk of the sympathetic nervous system and its connections with the spinal nerves concern the external morphological structure. However, the practical significance of the presented differences in structure are made especially clear when we consider the possible course of the sympathetic cell axons and the location of the peripheral neuron (synapse) of the sympathetic system.

We mentioned earlier that in the lateral cornua of the

spinal cord over an expanse from the eighth cervical to the second lumbar segment there is a collection of cells -- vegetative centers performing effector, vasomotor and trophic functions. The axons of the indicated cells come out of the spinal cord in the composition of the anterior roots. These preganglionar fibers (white connective branches) penetrate into the trunk of the sympathetic column. Part of them, which goes primarily to the internal organs, leaves the sympathetic trunk and ends in the prevertebral plexuses, where the peripheral neurons are located. However, part of the fibers ends in the sympathetic trunk, in whose ganglia are located the peripheral neurons which participate in the /395
innervation of the extremities. The axons of the peripheral neurons, the postganglionar fibers, leave the ganglia of the sympathetic trunk and penetrate into the peripheral nerves in the perivascular spaces of the large vessels (the perivascular nerves). An insignificant part returns within the composition of the posterior roots back to the spinal cord (return branches). The latter innervate the meninx and the vessels. This group of fibers is insignificant as compared with the former. It is considered that the sympathetic fibers (vasoconstrictors) leave the spinal cord in the composition of the anterior, and the vasodilatators primarily in the composition of the posterior roots.

Topographically the sympathetic centers of the spinal cord are distributed as follows: the eighth cervical and first-second, and partially also the third thoracic segment innervate the area of the head. Their peripheral neurons are found primarily in the superior cervical ganglion.

The thoracic segments (third, fourth, fifth, sixth and seventh) include cells which participate in the sympathetic

innervation of the thoracic wall and the upper extremity and neck. The tenth, eleventh and twelfth thoracic segments and the first and second lumbar segments contain cells which participate in the innervation of the lower extremity. Their /396 peripheral neurons are found in the ganglia of the lumbar and partially the sacral region of the marginal trunk of the sympathetic nerve.

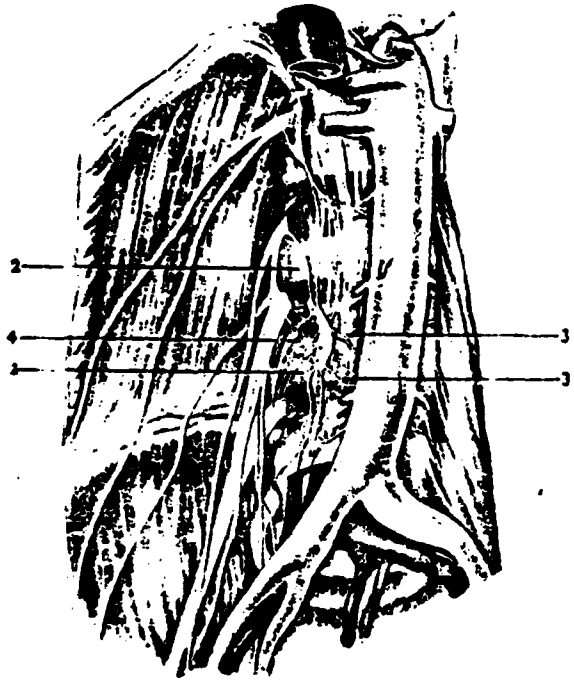


Fig. 155. The structure of the sympathetic (marginal) trunk of the sympathetic nerve in the lumbar region with concentration of ganglionic masses.

1 - sympathetic (marginal) trunk; 2 - ganglia; 3 - connective branches; 4 - intersecting connections; 5 - ganglionic inclusions along the course of the connective branches.

Thus, the preganglionic fibers which participate in the innervation of the upper extremity emanate from the spinal cord within the composition of the roots over the extent of the third-sixth, and sometimes also the seventh thoracic segment. Penetrating into the sympathetic trunk, these fibers end at the peripheral neuron, whose location varies. The post-ganglionar fibers reach the terminal territories within the composition of the peripheral nerves as well as in the form of periarterial nerve plexuses of the vessels.

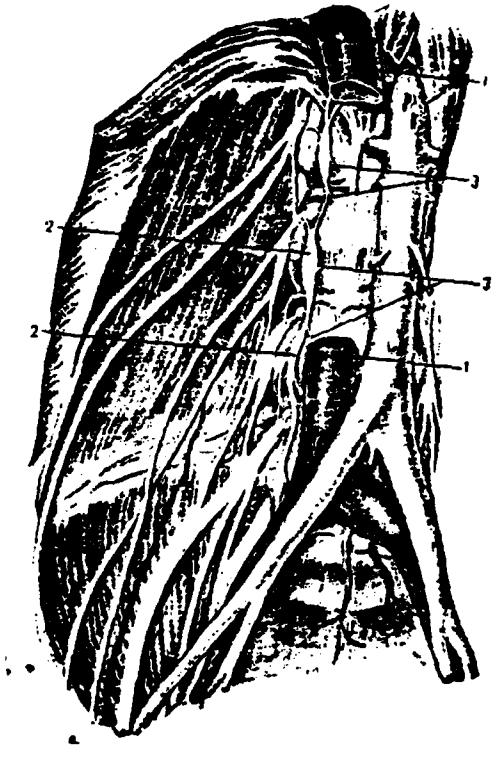



Fig. 156. Structure of the marginal trunk of the sympathetic nerve in the lumbar region with segmental location of the ganglionic masses.

As the studies of B. I. Lavrent'yev showed, the neurons may be dispersed along the course of the trunk as well as along its branches, as a result of which "mosaic" degeneration is observed in case of severance.

If we consider the differences described above, i.e., those cases when the segmental structure of the cervical sympathetic (marginal) trunk is observed, when the stellate ganglion is absent and when in the cervical region, aside from the inferior ganglion there is a middle ganglion and another series of small ganglia, the peripheral neurons which participate in the innervation of the upper extremities will be dispersed in the indicated ganglia of the lower part of the cervical region of the sympathetic nerve, and in two, /397 rarely in three upper thoracic sections. Consequently, the removal or injury to one of the ganglia in the segmental structure cannot always be clearly expressed in the disruption of secretory, vasomotor and pilomotor reactions.

If, however, the ganglionic masses are concentrated in a single thick stellate ganglion and consequently the peripheral neurons which participate in the innervation of the upper extremity are found primarily within its boundaries, then injury to the ganglion or its removal must inevitably be manifested at the periphery in terms of change in the functions indicated above. Here, however, we must consider the fact that even with the concentration of the ganglionic masses in a well-expressed stellate ganglion, its removal does not totally deprive the extremity of sympathetic innervation, since part of the fibers coming out of the spinal cord go together with the anterior and posterior roots into the peripheral nerves, by-passing the sympathetic trunk. Moreover, the postganglionic fibers whose neurons are found in the ganglion of the second thoracic and sometimes the third

root, penetrate into the nerves of the upper extremity, also by-passing the stellate ganglion.

Analogous relations are also observed in the area of the lower extremity. Here the preganglionic fibers proceed within the composition of the tenth, eleventh, twelfth thoracic, first, second, and sometimes third lumbar root.

The peripheral neurons are found in the ganglia of the lumbar plexus. The postganglionic fibers penetrate into the nerves of the lower extremity from the ganglia of the lumbar plexus through the connective branches of the first, second, third, fourth, fifth lumbar and first and second sacral roots.

With the segmental structure of the sympathetic trunk, the peripheral neurons which participate in sympathetic innervation of the lower extremity will be more or less uniformly dispersed in the ganglia and even on the individual connective branches. However, in cases of concentration of the ganglionic masses when there is one or two lumbar ganglia, they will be found within the boundaries of these ganglia and consequently their removal or injury will be more clearly expressed in the form of changes of vasomotor, effector and trophic functions at the periphery. This effect is more difficult to achieve when the peripheral neurons are dispersed.

Within the area of the lower extremity, as in the upper, complete desympathization cannot be achieved due to the presence of sympathetic fibers within the composition of the roots. These sympathetic fibers go to the periphery by-passing the sympathetic trunk. We may assume that the number of such fibers in the roots varies with the individual, which is why the degree of functional changes on the periphery varies with removal of the sympathetic ganglia. Moreover, the presence of such fibers may facilitate faster restoration

of the sympathetic functions, which is usually observed after operations and injuries to the sympathetic trunk.

It was noted above that the postganglionic fibers participate in the formation of plexuses which surround the walls of the arteries and veins of the extremities. Injury to the peripheral nerves, which contain vascular fibers, will undoubtedly be reflected on the function of the vessels, though only partially, since the intramural apparata may to a certain degree compensate for the loss in innervation on the part of the spinal nerves. Here, evidently, it is necessary to consider that the route of the vasomotor nerves to the periphery may vary. Sometimes they proceed primarily /398 within the composition of the spinal nerves, while sometimes they may be primarily within the composition of the vascular plexuses. This may evidently also explain the fact that vasomotor disruptions in spinal nerve injuries are not always and not in all individuals expressed in an identical degree. Aside from the sympathetic fibers, the formation of the perivascular plexuses may possible also include elements of the parasympathetic system, and therefore the peripheral vessels, like the skeletal muscles, have three sources of innervation.

From the material presented it follows that peripheral nerve injury represents an injury to all three systems -- the spinal, the sympathetic and the parasympathetic.

The above described anatomical differences in the structure of primarily the vertebral section of the sympathetic nervous system in which the surgeon must most often intervene with causalgia, reflexogenic contractures and other disorders associated with injury to the vegetative nervous system must always be considered in the analysis of clinical phenomena as well as in the process of surgical intervention.

If we consider that at the present time the basic requirement determining the success of surgical intervention on the vegetative system is the possibility of complete denervation of an area involved in the process, then the technique of the surgical interventions must be individualized depending on the character of the structure of one section of the vegetative nervous system or another.

In those cases when the stellate ganglion or the superior thoracic ganglia are clearly expressed and large (which is observed more often with concentrations of gangliose masses), denervation may be implemented without significant difficulties. This is equally true also for the lumbar region.

The surgeon encounters completely different conditions with dispersion of the ganglionic masses, when the primary ganglia are numerous and small or when a greater or lesser accumulation of ganglionic cells is found along the course of the connective branches. In such cases, the removal of one ganglion, regardless of whether cervical, thoracic or lumbar gangliectomy is being performed, will naturally not provide the desired denervation. The surgeon must remove a number of ganglia over a considerable extent, paying particular attention to the connective branches. Here it is necessary to consider that on the connective branches "auxiliary nodules" are located very close to the spinal nerve.

The indicated differences must be considered also in evaluating the immediate and long-term results of operative intervention. Their underestimation leads to discrediting the method of intervention, while the involved ganglia are not removed during the operation. The specifics of the distribution of gangliose masses in the peripheral regions of the vegetative nervous system (particularly in the vertebral) do not always

provide for the possibility of preganglionic sympathectomy, the outlooks on which are currently being reviewed by clinicians.

## The semiotics and pathogenesis of causalgia

Causalgia is a specific type of syndrome which develope in a huge number of cases with wartime traumas to the peripheral nerve trunks. It is characterized primarily by intensive pains of a burning character with a unique localization; secondly, by the intensification of these pains with irritation of the cutaneous receptors, as well as the receptors of another type; thirdly, by the intensification of pains in connection with emotions; fourth, by an increase in the emotiveness of the patients and fifth, by the favorable effect of cooling and wetting the skin on the pains.

Allusions to this type of syndrome have long been present. Thus, N. I. Pirogov during the Crimean and Caucauses campaign saw such cases, which he described under the name of "traumatic hyperesthesia". N. I. Pirogov notes all the basic characteristic traits of the causalgic syndrome -- intensity of pain, cutaneous hyperesthesia, changes in psyche, etc.

In 1864 and then in 1872, Veyr-Mitchel gave a more complete description of this syndrome, which he observed in wounded patients during the United States Civil War. He notes the burning character of the pains, the generalized hyperpathy, the psychical changes, vasomotor and trophic disruptions, the favorable effect of cooling and moistening. Here he assumption that vasomotor disorders at the periphery play a role in the pathogenesis of the syndrome. However, the works of N. I. Pirogov and Veyr-Mitchel did not attract the necessary attention and were subsequently totally forgotten. And when during World War I among the huge number of patients with wounds to the peripheral nerves there also appeared

wounded with causalgic syndrome, which at first was not properly diagnosed. These patients were mistaken for neurotics, even malingerers. And only in 1915 did the first works appear which again described the causalgic syndrome. Here the assumption was expressed that the mechanism of the origin of causalgia is reduced to the disruption of vegetative innervation of the peripheral tissues as well as the nerve trunks themselves. After this a number of works appeared which were devoted to the clinical treatment of causalgia, a clarification of its pathogenesis and a development of its therapy.

In the interval between World War I and the Great Patriotic War there were very few works devoted to causalgia, since during peacetime this illness in its expressed form develops very rarely. However, with the outbreak of the Great Patriotic War, cases of causalgia again came to be observed quite often, in connection with which there again appeared numerous works devoted to causalgia.

This problem was developed in particularly great detail /400 by Soviet neuropathologists, neurosurgeons and neurophysiologists, as a result of which at the present time not only has the clinical picture of causalgia been studied in detail, but also its pathogenesis has been clarified for the most part, and its conservative as well as operative therapy has been developed.

Injuries to the nerve trunks accompanied by the development of causalgia comprise only a small part of all the cases of nerve trunk injuries.

Table 39 /399

The relation of frequency of causalgic syndrome in injuries to the individual nerves

| Name of nerve | Percentage |
|---|---|
| Brachial plexus | 5.6 |
| Radial | 0.1 |
| Median | 2.8 |
| Ulnar | 0.6 |
| Median and radial | 2.2 |
| Median and ulnar | 2.2 |
| Median, ulnar and radial | 2.1 |
| Lumbosacral plexus | 4.3 |
| Sciatic | 6.2 |
| Fibular | 1.2 |
| Tibial | 3.6 |
| Fibular and tibial nerves | 1.1 |
| Sciatic and femoral | 5.5 |
| Nerves of the upper and lower extremities | 1.4 |

According to the materials for the development of illness /400 histories, the causalgia syndrome in peripheral nerve injuries was noted in 2.5% of the cases. From an analysis of this material we have been able to establish the frequency of injuries to the individual nerves (table 39).

It is evident from table 39 that in injuries to the sciatic nerve the causalgic syndrome is observed most often -- in 11.7% of the cases. The causalgic syndrome was noted almost as frequently in injuries to the median nerve -- in 9.3% (this also includes isolated and combined injuries to the indicated nerves). This syndrome was noted quite rarely in injuries to the ulnar nerve, and most rarely in injuries

to the radial nerve.

According to the materials of certain authors, the frequency of emergence of the causalgic syndrome in injury to the individual nerve trunks fluctuates. Thus, A. G. Molotkov feels that the cases of causalgia comprise 1.8% of all cases of peripheral nerve injury. A. V. Bondarchuk -- 4.0%, A. V. Gabay -- 18.0%, Stradyn' -- 2.0%, B. G. Yegorov -- 8.5%, L. A. Koreysha -- 2.0%, G. A. Rikhter -- 10.0%, L. G. Chlenov -- 1.0%, D. G. Shefer -- 12.0%. The variability of these data depends on two reasons. First of all, on the fact that part of the authors were dealing with such a small number of observations that it was impossible to establish correct percentage ratios and secondly on the fact that part of the authors relate all expressed pain syndromes to the causalgic group.

The manifestation of causalgia developed most often in injuries to the major nerve trunks. In a considerable majority of cases, causalgia developed with injuries to certain specific nerve trunks, specifically: on the upper extremity causalgia usually arose with injury to the median nerve, more rarely the ulnar; on the lower extremity -- with injury to the common trunk of the sciatic and tibial nerve. Here causalgia developed considerably more frequently with injury to the median nerve on the shoulder than on the forearm. Similarly, it developed more often with injury to the sciatic nerve on the thigh than with injury to the tibial nerve on the crus.

The affliction of all other nerves of the extremities was accompanied by manifestations of causalgia much more rarely. It developed even more rarely with nerve injuries on the torso and the head. However, causalgia sometimes developed also after an injection or a superficial cut on

the skin or after a bone fracture. In these cases, when small nerve branches were afflicted, causalgia developed most often with injuries to the tissues of the hand, particularly the fingers, as well as the foot.

The first painful sensations after nerve injuries usually appeared several days after the injury was sustained -- in most cases after 5-15 days. However, cases were noted when they developed also after 20-30 days, and even after 2-3 months. Cases have been described when pain sensations appeared 1-2 days after the injury, and even immediately after it was sustained.

The other symptoms of causalgia -- muscle atrophy, perspiration disorders, dystrophic phenomena on the part of the skin, fingernails, hair, etc. usually developed after the appearance of the pain sensations.

Pain sensations are primary in the clinical picture /401 of causalgia. These sensations are characterized first of all by a burning character. The patient feels as if the afflicted extremity has been placed into boiling water or engulfed in flames. In other words, the sensation which he experiences is similar to the sensation which is present in a burn. This burning character of pain sensations was the reason for designating this syndrome as "causalgia", i.e., "burning pain". However, aside from the burning sensation, patients often simultaneously experienced a different type of pain sensation, which was characterized by them as a sensation of painful compression of the extremity ("the hand is gripped in a vice"), sensations of painful vibrations within it, etc. The intensity of the pains in expressed cases is so great that the patient loses the capacity not only to perform any work, but even to deal with his environment, to wash himself, etc.

Extremely characteristic, almost specific for causalgic syndromes as compared with other pain syndromes is the topography of the pain sensations. At first with injury to some specific nerve it sometimes corresponds to the zone of distribution of its branches. In some cases it corresponds to the autonomous zone of innervation of the afflicted nerve, i.e., to that zone which the given nerve innervates without the participation of branches of neighboring nerves, as for example in injury to the median nerve -- to 3½ fingers and the corresponding part of the palm. In other cases it corresponds to the maximal zone of the afflicted nerve, i.e., to that zone where the afflicted nerve gives even an insignificant number of fibers, as for example with injury to the median nerve -- to the entire palmar surface of the hand. However, as a rule, in a short while the pains begin to appear also in zones which are not innervated by the injured nerve. Thus, for example, with injury to the median nerve the pains spread to the entire hand, and then to the forearm, brachium, and torso. Here, as indicated by certain authors, the pains on the torso with injury to the arm encompass the territory whose boundary at the top reaches the sphere of innervation of the first cervical root, i.e., to the upper part of the neck, and at the bottom -- to the area innervated by the sixth-eighth thoracic root, i.e., to the line passing somewhat above the umbilicus. With injuries to the leg, the pain sensations, if they spread above the point of injury, may encompass the entire surface of the leg and the area of innervation of the eleventh-twelfth thoracic segment, so that the upper limit of anesthesia passes at the level of the umbilicus.

If the painful zone on the arm or leg, spreading outside the zones of innervation of the afflicted nerve, does not fully encompass the indicated territory, but only a part of the extremity, then the boundary between the painful zone

and the zone without any pain sensations is usually formed by a line which more or less approximates a circle. As a result of this, the pain zones have the form of a glove, sock, etc. In part of the cases such a zone developes a certain time after the injury has been sustained, and in part of the cases -- from the very moment of injury. In these cases the painful territory from the moment of injury spreads to the zone which does not correspond to the sphere of innervation of the afflicted nerve.

With pains in the area of the hand and foot, pains on the palmar surface were always expressed much more strongly than on the dorsal surface.

Extremely characteristic for the causalgic syndrome is the phenomenon described under the name of synesthesialgia. It consists of the fact that, with the presence of pains in some part of the body, in the primary pain zone even insignificant stimulation of the receptors for overall sensitivity in other parts of the body intensifies the pain sensations in the primary pain zone. Thus, for example, with /402 injury to the right median nerve and pains of a causalgic character in the right arm, a pin prick or touch on the left arm, torso, etc. causes sharp pains in the right arm. Here the zones of synesthesialgia, or secondary pain zones, usually develop not immediately after the injury, but a certain time after it. With injury to some extremity, the secondary pain zone usually forms primarily on the opposite extremity of the same name, i.e., with injury to the right arm the pain appears when the left arm is touched or pricked with a pin. In other cases, the pain zone develops primarily on the other extremity of the same half of the body. For example, with causalgia of the right arm, pain sensation in it is provoked by stimulation of the receptors of the right leg.

The secondary pain zone may be limited to a single extremity. However sometimes it gradually increases and spreads over the entire body. In this case, touching any part of the body causes sharp pains in the primary pain zone.

In expressed cases of causalgia, pain sensations were also intensified from stimulation of the sensory organs. Bright light, noise, strong odors caused significant exacerbation of the pain sensations.

Extremely typical for causalgia is the intensification of pains when the afflicted extremities are heated and reduction of the pains when they are cooled. As a result of this, some patients in the presence of causalgia submerged the afflicted extremity in a vessel of cold water, where they held it for hours. Other patients packed the afflicted extremity in towels soaked in cold water, and would lie like this for days. In part of the cases the patients cooled by one means or another, aside from the extremity in which the causalgia was manifested, also the other extremities. More often with causalgia of one arm the patient also cooled the other, healthy arm. This facilitated the reduction of the pain sensations in the afflicted extremity. With causalgia of the lower extremities, when the condition of the patient improved to the point where he could walk, it was sometimes necessary to pour cold water into the shoe before putting it on.

The temperature of the water used to soak the extremity usually equalled 15-20°. Colder water often caused an intensification of the pains rather than their reduction. The decrease in pain with causalgia when the extremity was soaked in water is explained not only by its cooling. Some

patients who suffered from causalgia, in the period when the painful sensations decreased, soaked their fingers in glycerin or fat. The thin layer of these substances quickly took on the temperature of the fingers, but the pain killing action lasted for hours. Evidently, the layer of glycerin or fat acted in these cases as a pain killer because its presence reduces friction when the fingers touched various objects, as for example a pencil during writing.

In some cases, compression of the extremity above the zone of pain, which stopped the inflow of arterial blood, temporarily reduced the pain sensations. Also effective, but to a lesser degree, was sometimes the elevation of the afflicted extremity, which reduced its blood filling, hindered inflow and facilitated the outflow of the blood.

With an objective study of sensitivity in patients with the causalgic syndrome, it is always possible to find hyperpathy, i.e., increased sensitivity. It was found in studying all forms of sensitivity. Already a light touch with the finger or with cotton caused sharp pain in the patient, which was often perceived in a diffuse manner, i.e., not only at the point which was being stimulated, but also on the /403 surrounding areas of skin, sometimes over a rather lengthy extent. The subsequent stimulation of a number of points along the skin, which is achieved by drawing a finger or cotton along its surface, usually caused even more intense pain sensations. Similarly, pricking the skin, placing something hot or very cold on it caused strong, often diffuse pains.

The stimulation of the pain receptors of deeper tissues, which was achieved by means of compressing them, for example by compressing the muscles, was also painful, but usually in a lesser degree than stimulation of the cutaneous receptors.

The exception is presented by the joints, and sometimes also the major vessels, pressure upon which usually caused considerable pain. Pressure on the nerve trunks of the afflicted extremity caused not very intense pain.

Simultaneously with hyperpathy in an objective study of sensitivity it was sometimes possible to discover cutaneous zones with reduced sensitivity. All types of superficial sensitivity may be reduced. In studying deep sensitivity, no significant deviations from the norm were found.

The topography of objective sensitivity disruptions in general corresponded to the zone of pain sensations. Often in various areas of the primary pain zone there was observed a different state of sensitivity, as for example in some areas the reduction in sensitivity was clearly expressed, while in others it was weakly expressed or absent altogether. I. I. Rusetskiy directed attention to the fact that in some cases of causalgia of the upper extremity, tapping on the spinous processes of the IV-IX thoracic vertebra caused painful sensations in this area, as well as in the primary pain zone, particularly in the hand. When tapping along the spinous processes at the level of the X thoracic to the III lumbar vertebrae, however, analogous phenomena were observed with causalgia of the lower extremity. This fact is explained by the following: at the level from the fourth to the seventh thoracic segment are the sympathetic centers of the upper extremity, while at the level of the tenth to the third lumbar are the centers of the lower extremity. As a result of this, with over-stimulation of the sympathetic spinal centers it is sufficient to stimulate the sensitive endings of the vertebral column, which occurs when it is tapped and is transmitted along the meningal branch (ramus

meningeus) to the spinal cord, in order to cause a pathologically intensive discharge on the part of these centers, expressed in pain sensation.

The pain sensations of a unique character and with a unique topography are a basic symptom of causalgia. However, along with the pain sensations, in every case of causalgia it is possible to find also a disruption in the function and structure of various tissues of the afflicted extremities.

In almost all cases, the function and structure of various elements of the skin and its adnexa is sharply altered. Cutaneous blood circulation may be changed in various ways. In part of the cases the skin of the afflicted extremity is colored a bright red, which depends on the expansion of its precapillaries and capillaries. The skin temperature is elevated, which may be established by thermometry as well as simply by touch, since the difference in the temperature of the afflicted and the healthy extremity may reach up to 3 or more degrees. In part of the cases, the arteries of the extremity which are even more deeply located are expanded, which may be proven by means of platismographic study of the extremity, i.e., by measuring its volume.

However, expansion of the arteries and capillaries was /404 observed usually within the course of the first few weeks of the illness. In subsequent stages the hyperemia of the skin and the deep tissues of the injured extremity was usually replaced by their anemia due to spasm of the arteries and capillaries. Here the skin on the afflicted extremity became paler and colder than on the healthy extremity. However, in part of the cases anemia developed, evidently, from the very beginning of the illness.

In some cases, as pointed out by A. V. Bondarchuk, patients suffering from causalgia developed unique vasomotor crises. Bright red spots appeared in a definite zone, which increased and, merging, gradually spread over the entire zone, which was accompanied by a sharp intensification of pains in that same zone. This zone, as indicated by A. V. Bondarchuk, in causalgia of the upper extremities is delimited by the arm, neck, face, and upper part of the chest, i.e., the zone of innervation of the stellate ganglion.

Sometimes the skin took on a cyanotic coloration, which depended on the spasm of the arterioles with simultaneous expansion of the capillaries. The arteriole spasm entails a drop in pressure in the capillaries, into which blood subsequently comes from the veins, which is what conditions the cyanotic coloration of the skin. Sometimes in certain areas of the skin of an afflicted extremity it is possible to find manifestations of hyperemia, while in others -- anemia or cyanosis.

The condition of cutaneous blood supply was to a considerable degree influenced by the temperature of the surrounding environment. Hyperemia of the extremity which is observed upon presence in a room with high temperature, may be replaced by anemia or cyanosis with transfer to a lower temperature, for example, outside during the cold time of year.

A considerable disruption in the function of the perspiration glands was noted; in some cases an intensification of perspiration was observed -- the injured extremity was covered by abundant perspiration; in other cases a reduction in perspiration was noted -- the skin of the afflicted extremity was dry.

Disruption in the pilomotor function was manifested by the fact that goose bumps developed very easily on the afflicted extremity, which indicates pilomotor contraction. Sometimes it was sufficient to expose the afflicted extremity in order to cause this reaction, while on healthy extremities goose bumps did not appear under the same conditions.

In all cases of causalgia it is possible to see cutaneous trophic disruptions, i.e., disruptions in the structure of its various elements.

Noted on the part of the epidermis was an intensification in keratinization, as well as changes in its pigmentation in the direction of hyperpigmentation due to the increased production of pigment, as well as depigmentation due to its atrophy. The connective tissue skin layer was thinned due to its atrophy or became thicker due to hypertrophy or edema. In some cases small ulcers developed as a result of necrosis of cutaneous elements. This, however, was rarely noted. Sometimes a rash in the form of small blisters of the herpes type was noted.

In patients with causalgic syndrome who constantly soaked the afflicted extremities, other changes also occurred which were a consequence of skin maceration. The skin became pale, swollen, and its epidermis peeled off in places. The subcutaneous fatty tissue was often very prominent, and in later periods even sclerosed.

The structure of the skin annexa suffered considerably. In rare cases the cutaneous hairs on the afflicted extremity fell out. Usually, however, they underwent increased growth. Sometimes these hairs had a different, for example, darker /405 coloration than the hairs on the healthy extremity.

As a rule, the structure of the fingernails changed. They usually became thicker and grew faster. The anterior free edge of the fingernail was often bent downward so that the nail took on a shape reminiscent of a bird's claw. The fingernails usually became dull, lusterless, and sometimes became more brittle. When they were clipped, the fingernails crumbled and broke.

The trophics of deeper tissues of the extremities also changed. The bones usually became decalcinated, as a result of which they came out lighter on x-rays that the corresponding bones of the healthy extremity. The joints also changed. Their bursae and ligaments were sometimes edemic, and in later periods of the illness they turned into dense fibrose masses, as a result of which the mobility of the joints was severely limited. The process of turning into a dense cicatrical mass also spread to the aponeuroses, for example to the palmar aponeurosis. Its wrinkling created a picture close to that of the Dupuytren's contracture.

The muscles also participated in the illness process. They exhibited atrophy, usually weakly expressed, if the motor fibers of the nerve trunk were not afflicted and not accompanied by the degeneration reaction. In most cases the muscles were in a state of increased tonus. They were tense, and upon palpation were denser than normal. This hypertonia created a pathological position of the afflicted extremity. The arm was usually bent at the elbow joint and pronated. The hand was slightly bent. The fingers were bent into a fist or formed the so-called "obstetrical hand", i.e., the primary phalanges of the II-V fingers were flexed, while the middle and ungual ones were extended. The thumb was adducted, its primary phalanx was flexed, while the ungual was extended.

The active force of contractions was usually reduced, which to a considerable degree was explained by the painfulness of contractions, as a result of which the patient did not perform them. Sometimes fibrillar or fascicular twitching of the muscles was observed.

The tendinous reflexes on the afflicted extremity were increased, as well as increased. The mechanical excitability of the muscles was sometimes increased. If in the course of the nerve trunk injury the somatic fibers innervating the cross-striated muscles were also afflicted, then flaccid paralysis with atrophy accompanied by the degeneration reaction developed in the corresponding muscles.

The topography of all the above described disruptions in the structure and functions of the various tissues of the extremity in general coincided with the above described topography of the primary pain zone. In other words, these disorders spread either to part of the extremity with an upper circular limit or to the entire extremity with the adjoining part of the torso. Here, as a rule, the pathological phenomena were most clearly expressed at the periphery of the extremity, i.e., on the hand or the foot, while more centrally their intensity decreased. Sometimes they developed only in the distal sections of the extremities, and did not appear at all in the central sections. With the development of secondary pain zones, analogous phenomena developed also on their territory. For example, with causalgia of the right upper extremity, various pain manifestations developed also on the left upper extremity or on the right lower extremity. However, in the secondary pain zone they never reached such intensity and widespread distribution as they did in the primary pain zone. Most often a disruption of the vaso- /406
motor functions and the functions of the sweat glands was noted.

In some cases of causalgia there were disruptions in the functions of the internal organs as well. Thus, sometimes patients with the causalgic syndrome noted a feeling of pressure or pain in the heart, in some cases accompanied by tachycardia or bradycardia. These sensations usually arose in episodes in connection with intensification of pain in the arm or in connection with emotions. Since no symptoms of injury to the muscles and valves was found upon cardiac examination of such patients, we must assume that this is associated with disruption of cardiac innervation. Since the complaints of the indicated sensations in the area of the heart usually appeared with causalgia of the upper extremity, evidently in such cases they were conditioned by a disruption of the innervation in the system of the stellate ganglion, which sends impulses to the upper extremity as well as to the heart.

Sometimes patients suffering from causalgia exhibited a disruption in the activity of the digestive organs, manifested in nausea and diarrhea. In view of the absence of indications of organic injuries to the corresponding organs, and also in view of the fact that these manifestations disappeared quickly after the causalgia was cured, it is necessary to assume the neurogenic origin of these disorders also.

The psychical state of patients with causalgia changed in an extremely unique way. The attention of the patients was concentrated on the pain sensations, and all else was of little interest to them. In these cases, any stimulation of the sensory organs caused not only intensification of the pain in the afflicted extremity, but also severe psychical worry: the patients went into a state of agitation, sometimes screamed and cried. At the same time, any emotion which occurred even without stimulation of the sensory organs, as for example disappointment caused by receiving bad news,

caused a sharp intensification of the pain sensations.

Thus, the pain sensations caused inadequately intense emotional reactions, and the emotions evoked pain.

In some cases not only emotions, but also intellectual processes, as for example the emergence of certain ideas, influenced the intensity of the pain sensations. Thus, in some patients the idea of some dry object touching their afflicted extremity already caused an intensification of the pain.

All these specifics in the psyche of the patients together with hyperpathy explain the unique behavior of these patients. A patient with manifestations of causalgia strives to isolate himself from others, often asks that he be placed in a private room where there is the least amount of noise and which is kept semi-dark. If this is impossible, then he usually lies with a blanket over his head. He tries to have as little contact with those around him, including the medical personnel. He asks the doctor to touch him as little as possible, and if it is necessary, then to touch him with wet hands, etc.

Such behavior often caused such patients to be viewed as psychopaths or even malingerers. However, even in the most severe and prolonged cases of causalgia, if it is possible to totally eliminate the pain sensations by means of an appropriate operation, then the psychical shifts also disappear immediately -- the patient begins to act as a psychically normal person.

This proves that the psychical changes in patients suffering from causalgia do not arise primarily, but have a secondary onset in connection with the constant, extremely /407

intense pain sensations. It may be that in the genesis of psychical changes,the change in the vascularization of the brain, which depends on the disruption of its vascular innervation, plays a certain role.

It is easy to diagnose causalgia in its expressed forms. The causalgic syndrome must be differentiated from another pain syndrome which also develops in nerve trunk injuries which cause irritation of its sensory fibers. This syndrome, which may be called neuralgic, differs sharply from the causalgic. In the causalgic syndrome the pains bear a burning character, in the neuralgic -- a shooting or stabbing character. In the causalgic syndrome, cooling usually helps, in the neuralgic -- heating the afflicted extremity is helpful. In the causalgic syndrome, and this is particularly characteristic, the zone of pain sensations is significantly larger than the zone of innervation of the afflicted nerve and has the characteristic boundaries described above. In the neuralgic syndrome, the zone of pain sensation corresponds precisely to the area of innervation of the afflicted nerve. In the causalgic syndrome, secondary pain zones, or zones of synesthesialgia are formed, and hyperpathy develops in regard to stimuli acting on the special sensory organs. This is not observed in neuralgia. Finally, the psychical changes which are so characteristic for causalgia, are absent in neuralgia.

In view of all this it is possible to differentiate causalgic pain syndromes from neuralgic if they are sufficiently clearly expressed. However, difficulties may arise with less clearly expressed forms. In such cases, the criterion for solving the problem is the topography of the sensitivity disruptions and the vegetative disorders.

Difficulties may also arise in studying patients in the first days and even weeks, since in the appearance of pain sensations in patients with causalgic syndromes they may correspond at first to the area of innervation of the afflicted nerve, while the characteristic phenomena of causalgia (synesthesialgia, etc.) may still be absent. In such cases the problem is solved by observation of the subsequent course of the process. If within the course of several weeks the pains remain localized and no other phenomena characteristic of causalgia develop, it is safe to assume that they will not appear in the future. This gives us reason to establish the presence of the neuralgic syndrome.

The course and also the prognosis in causalgia is determined on the one hand by the degree of expression and distribution of the painful manifestations, and on the other -- by the rationality of the applied therapy. In mild cases the illness usually ends in recovery. However, even in these cases it usually lasts very long -- many months. In severe cases, sometimes even after operative intervention on the nerve trunk, the patients remain in the same condition for many years, and only sleep therapy or operative intervention on the sympathetic trunk leads usually to recovery in these cases.

The pathological-anatomical picture of causalgia is quite varied. In rare cases foreign bodies are found, bone fragments or shell fragments which have lodged near the nerve trunk or inside of it. In most cases there is scar tissue around the nerve trunk. Sometimes scars are also found inside the nerve trunk. These scars may also be numerous. Less often, neuromas are found during operation, located on the periphery of the nerve trunk, and sometimes in the center. Complete severance of the nerve trunk in

causalgia is rarely noted, although there are undoubtedly /408
such cases. Often, along with the nerve trunk, the nearby major vessels are also afflicted. In this case the vessel is surrounded by thick scar tissue which compresses it. In part of the cases the vascular walls also turn into a cicatrical mass, as a result of which there may be partial or complete obliteration of the vessel. Cases are noted when the vessels are significantly afflicted, and the nerve trunks only slightly. There is no parallelism between the degree of expression of anatomical changes at the point of injury and the intensity of the causalgic phenomena. Sometimes in very severe cases of causalgia during operation on the point of injury, insignificant changes are found, while in most cases of severe nerve trunk injuries with the formation of large neuromas, causalgic phenomena are totally absent.

The question of the pathogenesis of the causalgic syndrome is still controversial, although the differences of opinion which have existed on this question have recently considerably subsided. In general, all authors agree with the fact that the scar which remains after a nerve trunk trauma is usually the factor which creates the condition of over-stimulation in the receptor nervous system, which is manifested by pain, as well as in the visceral-effector nervous system, which is manifested by disruption of visceral-effector innervation.

The role of the scar in this regard was studied in particular detail and clarified by P. K. Anokhin, who showed that irradiation of impulses from one set of fibers to another may take place within the scar. This leads to the appearance of diffuse pain zones with affliction of a small number of fibers. The presence in the scar of a considerable number of

immature fibers deprived of myelin plays a significant role in this.

It is, however, necessary to note that causalgic phenomena may develop also immediately after the trauma. This indicates that the irritation of the nerve fibers, which usually occurs in connection with the presence of a scar in the nerve trunk or near it, may be at first the direct consequence of trauma to the nerve fiber.

In peripheral nerve injuries, pain phenomena of varying character may develop.

Why is it, then, that pains of a causalgic character develop only in a certain part of all the cases accompanied by pain phenomena? A number of hypotheses have been presented to answer this question.

In general, all these hypotheses may be divided into two groups.

The first group consists of hypotheses which view causalgia as a state of a particular form of over-stimulation of the pain perception apparatus.

Related to this group are primarily the hypotheses which examine the causalgic syndrome as a state of over-stimulation of the central pain receptor apparata -- primarily the apparatus of the tubercle of the thalamus. This over-stimulation, which is created in the tubercle of the thalamus due to the prolonged input of pathologically intensive pain impulses into it from the focus located on the periphery, then becomes fixed within it. A similar assumption was supported by M. A. Astvatsaturov, and at present this idea

is supported by P. K. Anokhin and L. G. Chlenov. The following arguments have been presented in favor of this assumption. First of all, the type of pain sensations characteristic of causalgia is very close to that observed in the thalamic syndrome, i.e., with organic injuries to the tubercle of the thalamus. Secondly, (this is pointed out by P. K. Anokhin), the topography of pain sensations and other pain manifestations in causalgia bears the above-described segmetal character, i.e., the margins of the afflicted fields form /409 a circular line. This is also inherent in thalamic afflictions. Third, the tubercle of the thalamus is a collector into which the conductors of all the sensory organs lead, which explains the hyperpathy in regard to stimuli acting on all the sensory organs which is observed in causalgia. Fourth, the tubercle of the thalamus and the hypothalamic region which is closely associated with it play a significant role in the emergence of affects. This explains the considerable influence of affects on the intensity of the causalgic phenomena.

Thus, according to this hypothesis, the essence of causalgia is reduced to a state of over-stimulation of the tubercle of the thalamus which, once triggered, is then retained regardless of the condition of the periphery. However, it is necessary to keep in mind the fact that the perception of pain sensation, as any other sensation, occurs only when the pain impulse reaches the cortex. As a result of this, without denying the role of the tubercle of the thalamus in the pathogenesis of the causalgic syndrome, it is necessary to add that the impulses from the tubercle of the thalamus, being in a pathological condition, come into the sensory centers of the cortex, where the focus of the static stimulation is created. This is what finally determines the semiotics of causalgia.

Also related to this group is the hypothesis proposed by the author, according to which the causalgic syndrome develops with injury of the visceral, i.e., the sympathetic, sensory fibers in the nerve trunk. These fibers originate in the cells of the spinal ganglia, enter the sympathetic trunk, pass a certain distance within it, and then exit from it and enter the nerve trunks of the extremities. These fibers are primarily conductors of pain impulses and enter the spinal cord through the posterior roots at the same levels from which the sympathetic effector fibers for the same extremity exit. In other words, the sympathetic sensory fibers from the upper extremities enter the spinal cord at the level of the fourth-seventh thoracic segment, where the sympathetic effector centers of the upper extremities are located, and from the lower extremities -- at the level of from the tenth thoracic to the second lumbar segment, where the sympathetic effector centers of the lower extremities are located. The injury of specifically these fibers is viewed as a reason for the development of causalgia. A series of arguments has been presented in favor of this assumption: first of all, the fact that the teritory of dispersion of causalgic phenomena corresponds to the territory of innervation not of the peripheral nerves and roots, but of the ganglia of the sympathetic trunk; secondly, the fact that the character of causalgic pains and other phenomena of causalgia corresponds with the character of manifestations observed in injury to the ganglia of the sympathetic trunk. Of course, this hypothesis is directed only at clarifying the question of why injury to the peripheral nerve in some cases causes pains of a neuralgic type, and in other cases of a causalgic character. However, it does not answer the question of the role of the central apparata of pain routing, i.e., the tubercle of the thalamus and the cerebral cortex, in the pathogenesis of the causalgic syndrome.

The second group is formed by the hypotheses which explain the origin of causalgia by the disruption of sympathetic innervation of the vessels, sensory nerve fibers, and nerve trunks of the extremities. Already Veyr-Mitchel presented the assumption that vasomotor disorders which are regular in causalgia, particularly vascular spasm, are a factor evoking pain sensations.

Other authors assumed that the disruptions of vaso- /410
motor innervation, particularly spasm of the vessels not only of the skin, but also of the nerve trunk, play a role in the pathogenesis of the causalgic syndrome. The ischemia of nerve endings and of the nerve trunk, which develops as a result of this is what creates their overstimulation.

A number of authors have expressed the opinion that the change in excitability of the pain receptors at the periphery is created by the disruption of the function of their sympathetic adaptational apparata. These assumptions are based on the works of L. A. Orbeli, who showed that the sympathetic fibers which wind around the endings of the somatic cutaneous receptors, the so-called Timofeev fibers, are an apparatus through which control of the sympathetic nervous system is implemented over the function of pain sensation perception, and it is specifically these fibers which determine the state of excitability of the pain endings. Based on this fact, a number of authors presented the assumption that in causalgia the disruption of the function of these adaptational fibers, which develops by reflex, creates that condition of overstimulation of the pain receptors which is manifested in terms of causalgic pains.

All the presented hypotheses had for their purpose to clarify the origin of pains in causalgia. However, the clinical picture of causalgia includes, aside from pains, also changes in the structure and functions of various tissues of the extremities. There can be no doubt that these changes are conditioned by the disruption of innervation to these tissues. This is proven by the coincidence of the area of pain sensations and these changes. These areas, as well as the area of pain, are considerably more extensive than the zones of innervation of the afflicted nerves. These disruptions may subsequently appear also on other, unafflicted extremities. Therefore there can be no doubt that they arise as a reflex -- due to the transition of the stimuli from the pain fibers to the visceral-effector. It is not known where the arch of these reflexes closes, in the spinal cord or higher, i.e., in the trunk, the hypothalamic area or in the cerebral cortex. It is possible that with different duration and intensity of the process it closes at different levels.

The hypotheses presented above for the pathogenesis of causalgia are quite varied. However in essence they do not contradict, but rather augment each other, underscoring the various moments of the process. In general, the mechanism of the origin of causalgia may presently be presented as follows: under the influence of an initial intensive stimulus at the moment of injury and subsequent irritation, which depends on the existence of a scar, overstimulation of the pain, and particularly the visceral-receptor conductors is created. As a result, there is a secondary emergence of a state of overstimulation also in the central apparata which perceive the pain sensation (tubercle of the thalamus, cortex). A reflex-pathological condition is created in all the visceral-

effector apparata at the various levels, particularly in the vasomotor and adaptational, which intensifies the pathological condition of the pain receptors at the periphery. This process develops with maximal intensity with injury to the nerve trunks which are richest in visceral fibers, i.e., the median and tibial nerve.

The fight against causalgia is not easy, and in some cases cures are affected only after operative intervention.

The methods of combatting the causalgic syndrome may be divided into three groups: pharmacotherapeutic, physiotherapeutic and operative.

Of the medicinal methods used in causalgia, the /411 various pain killers (pyramidon etc.) occupy first place. They sometimes have a certain effect, but in most cases this effect is insignificant and short-lived. An exception is morphine, which, however, should not be used since with the duration of causalgia addiction to it is inevitable. The morphine derivatives (codeine, ethylmorphine hydrochloride, etc.) may be given periodically, but with care.

Based on the observations that the capillaries are constricted during causalgia and considering the fact that this plays a certain role in the pathogenesis of causalgic pains, certain authors have proposed using injections of acetylcholine for treating causalgia. This primarily enlarges the capillaries. I. I. Rusetskiy also proposed histamine injections for this same purpose. V. N. Klyuchnikov introduced novocaine intravenously.

The treatment of causalgia by means of prolonged sleep was also proposed. This method was used by V. V. Zikeyev, Ye. M. Steblov and Kaminskiy, E. A. Asratyan and others with favorable effect.

The physiotherapy of causalgia consists of using galvanization, ion phoresis, and UHF. A. Ye. Kul'kov proposed mud therapy. He used low temperature mud and obtained favorable results with this treatment method.

Some authors recommend x-ray therapy in the form of irradiation the painful scar zone and the ganglia of the sympathetic trunk.

M. L. Borovskiy and other authors proposed introducing 1-4 $cm^3$ of 70% alcohol into the nerve below the point of injury in cases of causalgia. In 5 cases of M. L. Borovskiy this intervention led to recovery.

In evaluating the work capability of those suffering from causalgia, it is necessary to keep in mind that the patient only then becomes able to work when the manifestations of causalgia have fully disappeared. The patient must be hospitalized until only insignificant residual manifestations are present, which may be liquidated in the home environment with the condition of ambulatory treatment.

## The surgical treatment of causalgia

Burning pain, dystrophic manifestations and vegetative disorders -- this is the triad which characterizes causalgia and which makes it possible to differentiate it from other pain syndromes which arise after firearms injuries to the nerve trunks. It is quite evident that the sympathetic

nervous system plays a primary role in this dynamic process. Even Veyr-Mitchel characterized causalgia as being "vegetative neuritis". The "sympathetic" theory of causalgia was presented by Lerish during the First World War and for purposes of treatment proposed performing periarterial sympathectomy. In our country, A. M. Grinshteyn, B. G. Yegorov, F. M. Lampert, M. S. Margulis, V. M. Mysh and others adhered to this theory. On the basis of the clinical picture described in the preceding chapter and the indicated conceptions, the pathogenetic characteristics of causalgia a priori suggests itself: causalgia is the result of firearms injury to the endings of the sympathetic nervous system and the subsequent disruption of its effector and adaptational functions. Secondarily, the central pain perceiving apparata (the tubercle of the thalamus, the cortex) come into a state of excitation; the prolonged input of intense pain impulses from the focus of irritation at the periphery fixes this overstimulation. Thus a "splinter in the brain" arises (N. N. Burdenko). It is not by accident in the initial period of the Great Patriotic /412
War, when the Soviet soldier experienced the disappointment of retreat and misfortune, that gausalgia, as well as other reflex syndromes, was encountered significantly more often than in its second period, when the renouned Russian warrior, having broken the back of the Fascist beast, was victoriously concluding the war, bringing peace and freedom to the people. In the latter years of the war, the diagnosis of causalgia had all but disappeared. Such is the role of the central nervous system, and particularly the cortex, in the development of this malady. Morphologically we must assume that we are dealing with the formation of multiple tiny neuromas in the damaged sympathetic endings, in the cutaneous and in the mixed nerves which are rich in sympathetic fibers (median, sciatic and its tibial portion), in the perivascular and perineural intervals.

For the development of causalgia, it is not the massive injury of the sensory fibers that is important, but the involvement of some other nerve elements into the cicatrical-inflammation process, which give with a relatively small spatial injury a diffuse distribution of pain impulses which are unusual in character and in strength, with repercussive reflections at a distance, with defective vascular reactions and effector-secretory and trophic disruptions and finally, with general emotional-psychical changes in the personality of the patient. This is characteristic for injury to the sympathetic nervous system, which is basically constructed of bare amyelin fibers and therefore does not ensure the isolated passage of impulses, but creates conditions for their diffuse distribution. At the same time, it is specifically in the sympathetic nervous system that axon-reflexes are easily implemented which lead to vasomotor and neurotrophic disorders. With this reflex, as we know, the stimulation from any peripheral ending of the nerve fiber goes, by-passing the centers, to other branches of the same axon and, spreading antidromically, causes a certain effect at the periphery.

An interesting and completely original viewpoint was expressed by A. G. Molotkov. On the basis of many years of clinical-experimental study, he came to the conclusion that the pain conducting nerves of the extremity are not the ordinary nerves described in the anatomical handbooks, but special pain and trophic nerves, "pain companions" of the large mixed nerves, which are anastosed with them. Usually these are subcutaneous nerves. The intersection of these nerves (aside from the injured nerve trunk) as true conductors of pain sensations yielded good results for A. G. Molotkov in every case. Thus, in the basic controversial question on the pathogenesis of causalgia, its nature -- sympathetic or somatic -- A. G. Molotkov adheres to the somatic theory, and

considers vegetative disorders to be secondary derivatives.

In two cases of limited causalgia of the hand, the author successfully used neurotomy of the external cutaneous nerve of the forearm according to the principle of A. G. Molotkov. In one case the stimulation of this nerve with galvanic current during the operation caused typical, usually experienced burning pains in the patient's thumb and index finger, which is totally non-correspondent, as we know, with the zone of innervation of this nerve. These facts seem to confirm the data of A. G. Molotkov. However, they also allow another interpretation. The cutaneous nerves are vegetative to the same degree as they are sensitive. They are extremely rich in sympathetic fibers. In particular, the external cutaneous nerve of the forearm, we must assume, contains sympathetic /413 fibers along which in the order of the axon-reflex the unusual pain impulses are conducted which arise during causalgia of the radial portion of the hand. In this case, neurotomy of the cutaneous nerve represents a narrowed sympathectomy which eliminates the characteristic pain component of causalgia.

The methodology of A. G. Molotkov did not find widespread distribution. However, it deserves attention as an operation of the limited sympathectomy type and may be used as a preliminary operative intervention or even as an independent operation with so-called "minor causalgia". With an acutely expressed syndrome of "major causalgia" the neurotomy according to A. G. Molotkov is ineffective.

However, there is no proof or facts which would allow us to suppose that the sympathetic nervous system is a direct conductor of the pain impulses which are characteristic for causalgia.

Physiological studies (L. A. Orbeli) as well as clinical-experimental data (G. Kh. Bykhovskaya, I. M. Eydinova, F. M. Lampert) have shown that the sympathetic nervous system has only an adaptational effect on the receptors and the afferent apparata of the central nervous system and that it may change the excitability of the nearby sensory axons.

During the Great Patriotic War the most expedient in the treatment of causalgia was considered to be timely intervention on the sympathetic nervous system. The timeliness of the operation played a primary role, because the prolonged use of morphine and other narcotic substances turned the patients into drug addicts with the characteristic personality deterioration. In this severe stage of causalgia, even the most experienced psychiatrict could not establish whether the pain symptom complex was functional or organic.

However, before intervention on the sympathetic trunk it was considered necessary first of all to perform revision of the point of injury of the nerve trunk and, depending on what was found, to perform operative measures: 1) neurolysis and endoneurolysis, 2) resection of the neuroma and perineural nerve suture; 3) angiolysis and desympathization of the artery if it was involved in the cicatrical process; 4) resection of the vein if it was fused into the scar; 5) resection of the artery (arteriectomy) if it was thrombosed, and finally 6) removal of the fragment from the body of the nerve trunk or from the fatty tissue surrounding the trunk. It should be noted that during the war an original methodology of endoneurolysis was proposed -- the de-fasicularization of the damaged nerve (K. P. Chikovani). However, after such an operation, there is undoubtedly formed an endoneural scar in the nerve trunk. All the described measures were directed at eliminating the focus of irritation. The latter, either

in the form of a fragment or as a "generalizing" scar (P. K. Anokhin), or in the form of a point of stimulation of the sensory fibers by vegetative impulses, or else in the form of a focus for the emergence of axon reactions, is at the center of the mechanism which is active in the causalgic syndrome.

Also related to the preliminary measures is the novocaine block of the sympathetic trunk in various sections depending on the localization of the injury. Experience has shown that it is most expedient to perform a block of the lumbar sympathetic ganglia from the first through the fourth inclusive and of the first-third superior thoracic. Some [authors] have also cited the isolated anesthesia of the stellate ganglion. If the block temporarily eliminated all pain sensations and vegetative disorders, then this predetermined also the effectiveness of the operative intervention on the sympathetic trunk. Sometimes repeated blocks /414 of the sympathetic ganglia took on an independent significance as a means of treatment and led to recovery (A. S. Sharimanyan). If the first block had a favorable effect within the course of several hours (more than two), while the subsequent block gave an even longer effect, it could be assumed that with the further repeated application, a cure may be affected (V. N. Shamov).

Thus, the influence on the sympathetic trunk is also done by means of using anesthetizing substances which temporarily exclude the ganglionic cells. This is achieved by paravertebral block of the ganglia, for which 20-30 $cm^3$ of 0.5% novocaine solution is introduced into each ganglion. With causalgia of the upper extremity, it is usually introduced into the area of location of the stellate ganglion, and with causalgia of the lower extremity -- into the first-

fifth lumbar ganglion. For the reasons given above, A. M. Grinshteyn proposed blocking the fourth-seventh thoracic ganglia with causalgia of the upper extremity and the second-third lumbar ganglia -- with causalgia of the lower extremity.

Undoubtedly, by means of repeated injections (3-5) in mild cases and even in cases of moderate severity it was often possible to achieve significant improvement. As was already mentioned, certain authors even confirm that after repeated injections, a cure was achieved in certain cases (A. S. Sharimanyan).

Efforts at operative intervention on the spinal cord in the form of severing the posterior roots and even chordotomy did not yield positive results in most cases of causalgia. Considering the fact that the intervention on the periphery and the marginal trunk, as a rule, gave a favorable result, there is no reason to resort to operations on the posterior roots.

If we consider all the facts presented above, then the treatment of causalgia should be begun with operative intervention on the periphery (neurolysis, angiolysis), after which physiotherapy and paravertebral block should be performed. In severe cases, however, which are not subject to the indicated methods, intervention on the sympathetic trunk is indicated.

V. L. Pokotilo successfully used the alcoholization of the sympathetic ganglia as a treatment measure which yielded stable results. However, this methodology of prolonged chemical severance of the sympathetic paths is not without

some risk and to a certain degree contradicts the basic principles of neurosurgery -- the fineness and precision of operative influences. A. D. Speranskiy characterized the introduction of a chemical substance into the nerve tissue as "gross nerve trauma". He used it for purposes of the experimental reproduction of dystrophic processes.

If, however, interventions immediately in the region of the focus of irritation gave no effect, and if repeated block of the sympathetic ganglia gave no independent and stable therapeutic effect but gave only a temporary effect, then the question of operative intervention on the sympathetic trunk arose.

Gangliectomy usually gave a positive effect. The patients noted a complete disappearance of the tormenting pains already on the operating table. They were transformed in the direct sense of the work. Already on the second day after the operation the patient greeted the attending physician with a smile, became sociable and declined narcotics.

Certain authors, including A. V. Bondarchuk, recommended removal of the second, third and even fourth thoracic ganglion along with the stellate ganglion, and based this /415
position on the fact that the brachial plexus receives fibers not only from the stellate ganglion, but also from the second and third thoracic ganglion of the sympathetic trunk. Instead of removing the entire stellate ganglion, B. G. Yegorov proposed resectioning only its external edge from which the branches communicating with the trunks of the brachial plexus and the sympathetic trunk diverge. In this way, its connections with the cardiac plexus are retained.

Using this method of treatment, he achieved recovery as a rule.

Table 40

Operative interventions with injuries to the individual nerves, occurring with the causalgic syndrome

| Operation | Percentage |
|---|---|
| Neurolysis | 41.5 |
| Complete nerve resection with suture application | 21.3 |
| Partial nerve resection with suture application | 17.1 |
| Nerve revision | 3.3 |
| Desympathization | 8.1 |
| Operations on the sympathetic ganglia | 6.3 |
| Heterotransplant | 1.5 |
| Autotransplant | 0.9 |

Operations on the stellate ganglion in a significant majority of cases of severe causalgia were followed by full recovery. Thus, B. G. Yegorov obtained complete cessation of pains in all 39 cases, and A. V. Bondarchuk -- in all 34 of his cases.

However, the operation for the removal of the stellate ganglion also has certain negative aspects. First of all, individual cases of fatalities have been described (A. V. Gondarchuk, M. A. Nikitin, F. M. Lampert) resulting from technical errors during the operations. Secondly, it causes Horner's syndrome.

It should be noted that a favorable effect was often noted also after such preliminary operations as neurolysis, angiolysis, arteriectomy, extended desympathization of the

arteries, and primarily -- removal of a foreign body from the thickness of the nerve trunk. According to the materials for the development of illness histories, the following operative interventions were performed on the injured nerve trunks in cases of causalgic syndrome (table 40).

It is evident from table 40 what varied preliminary and operative interventions were used in relatively early periods after the injury.

According to the same data, the indicated operations were performed in the following times (table 41).

From table 41 we see that operative interventions on the individual nerves in cases of causalgia were performed in the first 3 months in 34.3% of the cases, in up to 4 months -- in 58.6%, and in up to 6 months -- in 92.8%. Significant improvement could not be noted during the period of hospital treatment. In 44.6% of the cases, no changes could be found after the indicated operative interventions.

Table 41 /416

Times of operative interventions on the individual nerves with the causalgic syndrome

| Time of operation (after injury) | Percentage |
|---|---|
| Up to 1 month..... | 3.6 |
| " " 2 months..... | 9.0 |
| " " 3 " ..... | 21.7 |
| " " 4 " ..... | 24.3 |
| " " 5 " ..... | 18.9 |
| " " 6 " ..... | 15.3 |
| " " 8 " ..... | 6.3 |
| " " 12 " ..... | 0.9 |

More effective are narrowed interventions due to firearms injuries and causalgia of the lower extremities. Causalgia of the upper extremities proceeds more severely and often requires expanded interventions on the sympathetic trunk. This is explained by the fact that sympathetic innervation of the upper extremities is more excitable (F. M. Lampert). For this same reason, causalgia developed more often after firearms injuries to the nerve trunks of the upper extremity.

Let us say a few words about the mechanism of action of economic operations. Every intervention on the sympathetic nervous system is comprised of exclusion phenomena and of neuroglandular shock, i.e., the inhibition of peripheral effector and receptor apparata (Ye. V. Babskiy, F. M. Lampert). If we consider the all-penetrating character of the sympathetic nervous system, then it becomes clear that with reduced sympathectomy the manifestations of exclusion are insignificant and the effectiveness of its action is reduced to neuroglandular shock, to repercussion phenomena. In a word, we are speaking of the positive results of "impact" upon the sympathetic nervous system (A. V. Vishnevskiy, A. D. Speranskiy).

In performing a gangliectomy for purposes of its greatest effectiveness, it is necessary to adhere to two principles presented in modern vegetology: 1) the intervention on the sympathetic nervous system must be complete in the sense of denervation of the corresponding area, i.e., it must be extensive and massive. Otherwise, the mediators formed by the retained nerve endings will act immediately also on the denervated tissues and will bring them into action; 2) the sympathectomy must be preganglionic, i.e., it

should be performed within the limits of the first neuron with retention of the postganglionic fibers. This methodology predetermines minimal sensitivity of the actuating organs to the actively physiological substances (mediators) circulating in the blood.

The first principle was propagandized in our literature by F. M. Lampert and approbated in practice during the Great Patriotic War. However, the second principle, proposed by A. M. Grinshteyn, should also be given its due. In 1939, A. M. Grinshteyn proposed performing preganglionic sympathectomy in cases of causalgia, i.e., without removing the sympathetic ganglion which is tied directly with the injured extremity, to severe its connections with the spinal cord. This is achieved by means of resectioning the third thoracic ganglion -- in causalgia of the upper extremity, and resectioning the second and third lumbar ganglion with causalgia of the lower extremity. A. M. Grinshteyn based his ideas on the assumptions that one of the pathogenetic /417 factors in causalgia is the disruption of adaptational and effector innervation. However, with disruptions in effector-visceral innervation it is specifically preganglionic sympathectomy, as indicated by the works of numerous authors, which is the most rational operation. Moreover, with causalgia of the arm this method does not create Horner's syndrome and is much less dangerous than the removal of the stellate ganglion. A number of authors (A. N. Bakulev, B. G. Yegorov, A. Yu. Sozon-Yaroshevich, V. N. Shamov and others) obtained complete and immediate cessation of causalgic symptoms, even in the most severe cases, using this method.

Long ago, S. N. Davidenkov already described the "dynamoses" which arise as a result of the separation of the

center from the periphery. Some foreign authors affirm that the peripheral effector apparata. secretory, vasomotor, pilomotor and others have an increased sensitivity to mediators as a result of postganglionic sympathectomy. However, in the mechanism of treating causalgia by desympathization, a primary role is played by the change in effector sympathetic functions, particularly the vasomotor. We have already spoken of the pathogenetic significance of the disruption of adaptation-trophic functions of the sympathetic nervous system and of the role of axon reactions which are so characteristic for overstimulation of the peripheral sympathetic system. Consequently, an extensive gangliectomy, be it preganglionic or postganglionic, including the corresponding section of the sympathetic nervous system which is in a state of overstimulation, may solve the problem of treating causalgia. It is interesting that even periarterial sympathectomy performed over a great extent (12-15 cm) and being exclusively postganglionic, gave a good effect, which was confirmed especially in the works of Lerish.

If, finally, we speak of the conception of M. I. Astvatsaturov - P. K. Anokhin (thalamic injury -- efferent impulses to the periphery through the sympathetic nervous system), here too a gangliectomy in any form will play its role as a means of mass exclusion.

The experience obtained in our country tells us that a positive effect in treatment was obtained with the application of postganglionic as well as preganglionic sympathectomy.

Thus, during the Great Patriotic War, the following interventions were performed on the sympathetic nervous system in cases of causalgia -- periarterial sympathectomy,

sometimes with resection of the vein of the same name, lumbar gangliectomy (the second-third lumbar ganglion), stellectomy and upper thoracic gangliectomy (the second, third, fourth thoracic ganglion).

Here are several general comments on the technique and principles of operations performed on the sympathetic nervous system which have been worked out during the war. The primary and, perhaps, decisive significance in the effectiveness of these interventions belongs to precision, minuteness and strict anatomical sequence in performing the operation. In the literature, as well as in the comments of those engaged in neurology and neurosurgery we may encounter such terms as "twisting out" the sympathetic ganglion. Obviously, such gross and primitive technique is unacceptable. It usually entails the formation of neuromas at the point of breakage of the sympathetic trunk. New focal points of irritation are created, and the picture of causalgia may be complicated. Aside from this, such gross trauma to the nervous system may serve as an inadmissible clinico-experimental reproduction of dystrophic disorders. All the branches, even the smallest, should be /418 intersected with a sharp and thin scalpel.

Only correct anatomical orientation and sequence led to the proper solution of the operative problem and prevented against injury to the minor and major vessels. Slight but difficult to stop venous hemorrhaging, rather significant and sometimes insurmountable arterial hemorrhaging turned these interventions into risky operations which moved the basic therapeutic task into the background. Periarterial sympathectomy is also unjustly considered a simple and easy operation. "Stripping" the artery by means of pinching and piecing the adventitia is a gross and erroneous intervention

which leads to the formation of multiple irritation centers on the vascular wall and gives a completely opposite "therapeutic" effect, i.e., it causes a deterioration of the condition. It is necessary to remove all the perivascular fatty tissue together with the adventitia in a single layer so that the circular muscle fibers are visible to the eye. The vessel takes on a greyish color and is uniformly contracted or expanded and begins to pulsate more noticeable. Only then has desympathization of the artery been performed properly.

The following observation (A. N. Bakulev and F. M. Lampert) is instructive in this respect: firearms injury of the sciatic nerve, causalgia. The lumbar gangliectomy performed at the previous stage did not yield any effect; on the contrary, dystrophic disorders developed on the foot and the pains intensified. A properly performed expanded desympathization of the femoral artery gave significant improvement. The possibility is not excluded that the gangliectomy was technically improperly performed.

The methodology of the lumbar retroperitoneal gangliectomy. The dextral lumbar gangliectomy. First stage. The cutaneous incision is drawn from the end of the XI rib downward through McBurney's point, and then to the midline, stopping short of it by 3-4 cm. In accordance with the incision, the external oblique muscle is dissected, and the external edge of the musculus rectus sheath is notched. Sharp hooks are used to retract the edges of the external oblique muscle, and the internal oblique muscle is dissected along the fibers for its entire extent along the imaginary line drawn from the anterior spine of the superior iliac bone obliquely upward to the midline to the level of the body of the II lumbar vertebra; at the same time, the transverse abdominal muscle

is also dissected. The edges of these muscles are extended with semi-circular retractors upward and downward.

The second stage. Thus, the abdominal wall is opened "in cellular fashion" by alternating incision. Then the transverse fascia is cut and with a movement of the hand inserted into the iliac fossa, the peritoneum is slightly moved away from the posterior abdominal wall, retracted to the midline and obliquely upward. With this methodology there is never any damage to the peritoneum, which unfavorably disrupts the smooth course of the operation. The musculus psoas major is exposed with the genitofemoral nerve lying on it, and then also the inferior caval vein, which is usually hollow and grey in color, not blue as depicted in anatomical manuals. A wide retractor is used to hold the peritoneum together with the viscera in the indicated position, and one more retractor is inserted into the upper corner of the wound transversely, which serves to move the kidney along with the perirenal fatty tissue upward. Good exposition is obtained.

The third stage. The loose fatty tissue is separated by the blunt method between the inferior caval vein and the internal edge of the musculus psoas major. The inferior caval vein together with the peritoneal sac is slightly /419 retracted to the midline, after which the external-lateral surface of the vertebral bodies is exposed and at the very point of attachment of the tendinous peduncles of the musculus psoas major above the iliac vessels, the sympathetic trunk is exposed. Unlike the nearby lymphatic vessels and ganglia, it is immobile and, like a string, stretched directly over the bodies of the vertebrae. Simultaneously with the retraction of the inferior caval vein, the nearby fatty tissue and the lymphatic nodes to the midline, wide retractors are

used to move the perirenal fatty tissue and peritoneum upward. Then Zuckerkandl's fascia is found, which spreads in the form of an arch from the musculus psoas major to the anterior surface of the superior lumbar vertebrae. This thick fascial layer is dissected, a retractor inserted in the formed fissure and, lifting upward, the superior-lumbar section of the trunk is exposed. With such exposition, visible on the anterior-lateral surface of the vertebral bodies at the margin of the musculus psoas major is the lumbar section of the sympathetic trunk from the second to the fourth lumbar ganglion inclusive and with lumbar veing and arteries intersecting it. These vessels pass sometimes in front, sometimes behind the trunk. Isolation of the lymphatic nodes and plexuses should be done very carefully and gently, under no circumstances crushing the lymphatic glands or tearing them. It is quite evident how dangerous the mobilization of infection and leakage of infectious lymph may be. The sympathetic trunk is usually a dull grey color, sometimes with a pinkish tinge, and the ganglia vary in size (1.5 x 0.5 cm or less). Diverging from the second lumbar ganglion are connective branches going in a transverse direction and upward, which makes it possible to determine it as the second, while from the ganglia which are located lower the branches usually diverge downward, sometimes in a transverse direction, but never diverging upward.

The fourth stage. Several threads are passed under the trunk at various sections. Long scissors, better a scalpel, is used to intersect usually the short connective branches of the second lumbar ganglion, which are easily visible with light and tonic pulling on the thread holders. The trunk which is isolated by this method in the superior lumbar region is intersected above the upper pole of the second ganglion. This moment is performed primarily to

avoid the development of axon reflexes during further manipulations, which may have an unfavorable effect on cardiac activity (L. A. Orbeli, N. V. Rayeva). In the mid-lumbar region the connective branches are longer, and here it is much easier to isolate the trunk, which is done rapidly. The trunk is isolated almost to its intersection with the isiac vessels. Not only are the connective branches intersected, but also the internal branches leading to the inferior caval vein and to the aorta, to the iliac vessels, to the viscera, and finally, the branches going under the aorta and caval vein to the other side in the form of commissures. Diverging immediately above the major vessels outward from the trunk is a large connective branch which goes to the rear under the musculus psoas major. Its intersection concludes the isolation of the lumbar region of the trunk, which is intersected at this level. In the described isolation of the trunk, it is necessary to avoid injury to the lumbar vessels, which sometimes creates serious complications in the course of the operation. If the vessels intersect the trunk in front of it, then by the method of tunnelization, after precise isolation and dissection of all the branches, the trunk is taken out from under the vessels. With such implementation of this stage, the operation proceeds without blood and without complications. If a small vein is damaged from the system of lumbar veins, hemorrhaging is completely stopped by the pressure of a tampon for a period of 2-3 minutes. Damage /420 to the lumbar artery requires the application of a ligature, which to a certain degree is difficult due to the depth of the operative field.

The fifth stage. Having made sure of complete hemostasis, the surgeon removes the deep retractors. Some surgeons administer 100,000 - 200,000 units of penicillin into the trunk bed. Catgut sutures are applied to the

muscles and aponeuroses. A closed suture is applied to the peritoneal wall. An aseptic bandage is applied. Most surgeons performed the operation under morphine-hexenal-ether narcosis (0.5 $cm^3$ hexenal, 100-150 $cm^3$ ether, 1.5 $cm^3$ 1% morphine) with the patient lying on his back with moderate incline of the table according to Trendelenburg and on his side facing away from the surgeon.

The methodology of left-sided lumbar gangliectomy. This is a mirror image of dextral gangliectomy. However, here are specifics in the location along the aorta of the large lymphatic aortal plexus, while the periarterial fatty tissue is more expressed and thicker than on the right side.

Anatomo-topographical specifics. The sympathetic trunk in its lumbar region is located immediately on the anterior-lateral surface of the vertebral bodies at the point of connection of the tendinous peduncles of the musculus psoas major and is fixed with a fascial layer to the vertebral bodies. On the right side it is covered by the inferior caval vein, and on the left it lies slightly to the outside of the aorta. On the contrary, the lymphatic nodes, unlike the sympathetic, are located more superficially. They are mobile and considerably larger. If we adhere to these orientation indicators, then it is not difficult to differentiate these formations. Moreover, the lumbar veins which are located transversely in relation to the trunk and accompany the communicating branches which go down under the arcades of the psoas muscle, are also a good anatomical orienting specific feature. Obviously, the thin nerve trunks (genitofemoral nerve) which are found on the anterior surface of the musculus psoas major cannot

be mistaken for the sympathetic trunk.

The considerable variability in the structure of the trunk, as well as the number of ganglia, are well known. Observations have shown that a more or less precise correspondence between the number of ganglia and the exposed vertebral bodies may be established in only 50% of the cases (Institute of Neurosurgery).

Let us present a description of a slightly different variant of the technique in lumbar sympathectomy, which was also widely used during the Great Patriotic War.

The operation was performed under local novocaine anesthesia. Three stages of anesthesia were distinguished: 1) infiltration local anesthesia of the soft tissues with 0.5% of novocaine solution, 2) interosteal anesthesia using 2% novocaine solution, and 3) absolutely mandatory anesthesia of the marginal trunk of the sympathetic nerve and the removed ganglia with 2% novocaine solution immediately after their exposure and before starting their isolation.

Exposing the retroperitoneal space, in this method the muscles were intersected or, better still, bluntly separated along the course of the fibers.

To expose the retroperitoneal space by means of intersecting both oblique and the transverse muscle, the cutaneous indision was started from the external margin of the latissimus dorsi, proceeding parallel, 1 cm below the XII rib, and ending at the external edge of the sheath of the musculus rectus abdominis at the level of the umbilicus or somewhat lower. Then the muscles were dissected by layer along the incision line. After broad retraction of the /421

intersected muscles, the peritoneum was bluntly and rather broadly layered away from the lateral and posterior abdominal wall. For this purpose it is best to use tampons soaked in 2% novocaine solution. The exfoliation of the peritoneum from the posterior wall of the abdomen to the midline was done by exposing the median edge of the musculus psoas major and the external part of the anterior surface of the vertebral bodies. Only after sufficient exposure of this region, which is indicated by the diaphragm peduncles which are evident here, is the isolation of the sympathetic trunk and its ganglia begun.

The peritoneum separated from the midline was held with the hand in such a way that the fingers reach the vertebral bodies. Sometimes already with this the trunk of the sympathetic nerve and its ganglia became clearly visible. In some cases, however, it was necessary to first separate the fatty tissue which is located here. After exposing the sympathetic trunk and before isolating it, a silk thread was passed under the trunk and it was carefully liften. Then anesthesia of the nerve and its ganglia had to be performed using 2% novocaine solution.

The trunk of the sympathetic nerve was grasped with long thin forceps at the upper end of the region marked for removal, and the cut was made directly under the forceps. Then, gradually raising the forceps and cutting the connective branches which are being pulled, the trunk and its ganglia are isolated for the necessary extent. After this the trunk was cut at the bottom. The wound was sutured closed by layer using interrupted silk sutures.

The exposure of the retroperitoneal space to perform sympathectomy without intersecting the muscles of the peritoneal wall is based on by-layer blunt separation of

the muscles along the course of their fibers. This operation may be done by means of various cutaneous incisions. It is rather important to create a broad enough access, and therefore, naturally, the separation of each of the muscles of the peritoneal wall should best be done at that point where these muscles are the longest. Having broadly retracted the split muscles using hooks, further access to the sympathetic nerve is implemented as described above.

The methodology of the cervical-thoracic gangliectomy (stellectomy). Local anesthesia with 0.25% novocaine solution is used. There is anesthesia of the cervical plexus with the addition of infiltration anesthesia in the region of the supraclavicular triangle.

First stage. The cutaneous incision is made parallel to the clavicle, 1½ finger widths upward from it. After dissection of the subcutaneous muscle and the external jugular vein, the external peduncle of the sternocleidomastoid muscle is cut between two ligatures, while the musculus omohyoideus is intersected and taken on the ligatures (this muscle should be sutured in closing the wound!).

Second stage. The sternocleidomastoid muscle with its neurovascular fascicle is retracted to the inside with blunt retractors. The vagus nerve will show through the taffy tissue of the vascular sheath. This moment should be fixed so that in subsequent manipulations on the sympathetic trunk the troublesome question will not arise, are we not dealing with the vagus nerve? The following exposition is obtained at this stage. The sympathetic trunk shows through the thin sheet of prevertebral fascia; the diaphragmal nerve is visible on the anterior scalene muscle, and runs in an inferior-oblique direction; at the level of the sixth trans-

verse process passing in a transverse direction is the inferior thyroid vein and artery, whose pulsations are visible to the eye.

Third stage. The prevertebral fascia is opened, and /422 then the cervical sympathetic nerve is exposed. It is grey in color with characteristic expansions and plexuses which distinguish it from the thoracoabdominal nerve which is located to the outside on the anterior scalene muscle, from the more superficially located and larger vagus nerve which is white in color and connected with the internal jugular vein, and finally from the descending branch of the sublingual nerve -- a thin nerve trunklet lying on the anterior surface of the neurovascular fascicle. The inferior thyroid artery is ligated if it is located in front of the trunk or passes through the opening formed by it. The median cervical ganglion is usually located at this level. A thread holder is passed under the sympathetic trunk.

Fourth stage. A thick pea-shaped tampon is used to isolate the vertebral vein and, retracting it to the outside, the vertebral artery is isolated. Both vessels are retracted to the outside with small hooks. This exposes the bed of the stellate ganglion, which is tied with the trunk located above by a thin branch; diverging to the inside of the stellate ganglion is the inferior cardiac branch, and to the outside and downward -- the loop of Vieussens, which encompasses the subclavian artery and behind it again connects with the stellate ganglion. In the nerve branch plexus, in front of and superficially to the stellate ganglion, an auxiliary ganglion is often located. The exposition at this moment is as follows: the vertebral vessels are retracted to the outside, a second "hook" is inserted in the lower

corner of the wound which retracts the fatty tissue together with the carotid artery and with the point of insertion of the thoracic duct (if the operation is from the left). The latter is located to the outside and superficially of the stellate ganglion. Downward and to the front of the stellate ganglion is visible the upper edge of the pulsating subclavian artery and the point of divergence of the vertebral. The intersection of the anterior scalene muscle (B. G. Yegorov) provides an even broader access.

Fifth stage. Anatomical forceps are used to isolate the stellate ganglion and subsequently all of its branches, with the ganglion being grasped by a special "nerve" hook or a thread which has been passed underneath. All the branches, including also the vertebral nerve which leads upward and goes into the canalis transversalis, are intersected using visual judgement, each individually. Finally, the ligaments going from the inferior pole of the first thoracic ganglion (i.e., the inferior region of the stellate ganglion) to the second thoracic ganglion are intersected. The intersection is performed with ophthalmic scissors. Only the thin branch connecting the stellate ganglion with the cervical sympathetic trunk is left intact. The cervical sympathetic trunk is intersected at the level of the central cervical ganglion, and this concludes the operation for cervical-thoracic gangliectomy.

Sixth stage. Hemostasis. Catgut sutures are applied to the external peduncle of the sternocleidomastoid muscle and to the musculus omohyoideus. Similar sutures are applied to the subcutaneous muscle. The skin is sutured and an aseptic bandage applied. If all the described manipulations are performed strictly anatomically and the sequence indicated above is maintained, then the operation proceeds

completely without blood, while the thoracic duct does not even get into the operative field. The moment of isolating the stellate ganglion and its extirpation are extremely painful and are accompanied by characteristic pains irradiating into the scapula, in the area of the heart, and into the arm.

Hexenal narcosis, as with all cervical operations, is counterindicated.

Anesthesia and the method of access to the stellate ganglion (used by B. G. Yegorov since the beginning of the Great Patriotic War).

The position of the patient is on his back with a /423 cushion under the uppermost part of the back, the head is abducted to the opposite side, the back of the head resting on a soft cotton-gauze ring and the head fixed to the stand with adhesive tape.

A half hour before the start of anesthesia, 1-2 $cm^3$ of morphine solution is administered subcutaneously. The anesthesia is begun in the projectional point of exit under the skin of the cervical plexus nerve endings at the external edge of the center of the sternocleidomastoid muscle extension. Introduced into this point, penetrating with a long thin needle to the muscle edge, is 20 $cm^3$ of 2% novocaine solution. Then the needle is pushed deeper through the entire thickness of the belly of the anterior scalene muscle until its point stops at the transverse processes of the cervical vertebrae. Changing the syringe to 1% novocaine solution, the direction of the needle is sharply altered, giving it a position almost parallel to the length of the vertebral column and moving it downward by

7-8 cm and all the while sending the anesthetizing solution along the course of the needle. With this manipulation, almost as a rule, paresthesia occurs in the brachial plexus. Depressing the needle to the indicated depth, 40 $cm^3$ of novocaine solution are introduced into the area of the plexus. Then standard infiltration anesthesia is performed along the course of the cutaneous incision. After performing the anesthesia, at least a half hour should be allowed to elapse before beginning the operation. Then, as a rule, good anesthesia has set in, which is maintained for hours and enables the performance of the most complex and prolonged operations in the area of the brachial plexus. The described method, unlike many others performed in surgery on the brachial plexus, differs in that the movement of the needle is performed always in the region of the course of the brachial plexus trunk, and its anatomical course is such that the injury of major blood vessels and injury to the cupola of the pleura is completely excluded.

The incision is begun somewhat above the point of attachment of the external peduncle of the sternocleidomastoid muscle and drawn to the outside and somewhat to the rear, following the course of the skin folds in the supraclavicular space. The length of the incision is no more than 10 cm.

After incising the skin and the subcutaneous fatty tissue, the fibers of the supracutaneous muscle are transversely dissected along with the endings of the supraclavicular nerves which penetrate through the thickness of this muscle. Under the cutaneous muscle in the thin layer of fatty tissue the external jugular vein and several of its branches which pass here are ligated and intersected.

Further, the incision penetrates through the fascia covering the sternocleidomastoid muscle, exposing the edge of its external belly and the fatty interfascial lining of the supraclavicular triangle. The lymphatic glands which are often encountered here should not be cut, but should rather be coagulated. The described fatty clump should not be removed, but broadly retracted to the sides, so that it may be used in suturing the wound. Lying begind it here is the musculus omohyoideus, which lodged in the thickness of the fascia. This muscle must be restored in suturing the wound, therefore its ends should be taken up on threads and separated. The role of this muscle is often underestimated, while it is known that its contractions stretch the fascia covering the major veins and protect them from compression when the neck is turned.

The edge of the sternocleidomastoid muscle is dissected with scissors in its lower third, closer to its tendinous part. After the indicated incisions, the lower third of the belly of the anterior scalene muscle becomes clearly visible, with the thoracoabdominal nerve located behind it.

An elevator retractor is slipped under the scalene muscle and its belly is gradually dissected in portions using a knife. Here it is necessary to keep in mind the fact that the truncus thyreocervicalis remains forward at /424 the internal edge of this muscle. Therefore, it is necessary to very carefully separate the tissue in this area by the blunt method. After the anterior scalene muscle is dissected, the major jugular vein, which is covered with fascia, is well contoured, and visible in the depth of the wound -- the fascia covered and pulsating subclavian artery and the a. and v. transversa colli which pass through the fascia which is visible here. These two small vessels must be

ligated and cut. Sometimes it was possible to proceed without cutting them. The indicated two small vessels are a good recognition point for the costopleural ligament which is also located here, whose laceration usually leads to opening of the pleural sac and the pneumothorax. This ligament must be cut with scissors.

Somewhat medially and deeper from the point of ligation of the transverse artery it is necessary to begin the blunt isolation of the subclavian artery arch. Further, using blunt sectioning, the way is paved medially between the clearly visible subclavian artery and the trunks of the brachial plexus. Here, a blunt hook (surgical spatula) is used to retract downward the subclavian artery, which lies on the pleural cupola, and to bring to the midline, also with a blunt hook, the fascia-covered neurovascular fascicle of the neck (the vagus nerve, the internal jugular vein, and the common carotid artery). At a distance of no more than 1-1.5 cm from the dissected edge of the anterior scalene muscle in the depth of the wound, the vertebral vein and artery, diverging from the subclavian artery, are well isolated. The vertebral artery is encircled from the front by thin strands of the sympathetic trunk. Often the lower edge of the inferior cervical ganglion is clearly visible. Using the trunklets of the sympathetic nerve, sectioning is performed along them downward behind the arch of the subclavian artery. Isolating and moving aside the fatty tissue in this area behind the point of divergence of the vertebral artery from the subclavian artery, immediately at the junction of the I rib with the articular surface of the I thoracic vertebra is where the stellate ganglion is isolated. The ganglion is impregnated with 2% novocaine solution, which causes it to stand out even more clearly in the surrounding tissues. After anesthesia, the ganglion is grasped with

a "nerve" hook and slightly uplifted. During this manipulation, its connective branches to the trunks of the brachial plexus and the branches going downward to the cardiac plexus are clearly visible. It is interesting that the intersection of the connections between the ganglion and the trunks of the brachial plexus already stops the causalgic pain, which only partially subsides with anesthesia of the ganglion itself. Having freed the ganglion from the connections with the trunks of the brachial plexus, its connections are severed from the trunklets which lead into the cervical part of the sympathetic marginal trunk. Then, carefully pressing the arch of the subclavian artery together with the pleural cupola downward, it is easy to penetrate into the upper mediastinum and together with the stellate ganglion it is possible by this means to also remove the second thoracic ganglion.

After removal of the ganglion and the most thorough hemostasis, the wound is sutured. The scalene muscle, however, should not be sutured so that the subsequent scar formation within it does not cause constriction of the interscalene fissure and bring on the symptom of the scalene fissure (scalenus syndrom). The edge of the notched sternocleidomastoid muscle is sutured, the musculus omohyoideus is sutured, the fatty lining of the supraclavicular triangle is sutured and further by layer -- the fascia, the cutaneous muscle, and the skin.

After this operation, as a rule, the causalgic pains ceased and not a single fatality was noted (B. G. Yegorov).

Upper thoracic gangliectomy (third thoracic ganglion) /425

First stage. The cutaneous incision 10-12 cm in length is started at the level of the first spinous process 5-6 cm

away from the midline of the spinous processes. The trapezoidal and rhomboid muscles are dissected along their fibers, then the fascia lumbodorsalis and partially the longitudinalis dorsi are dissected (fig. 157).

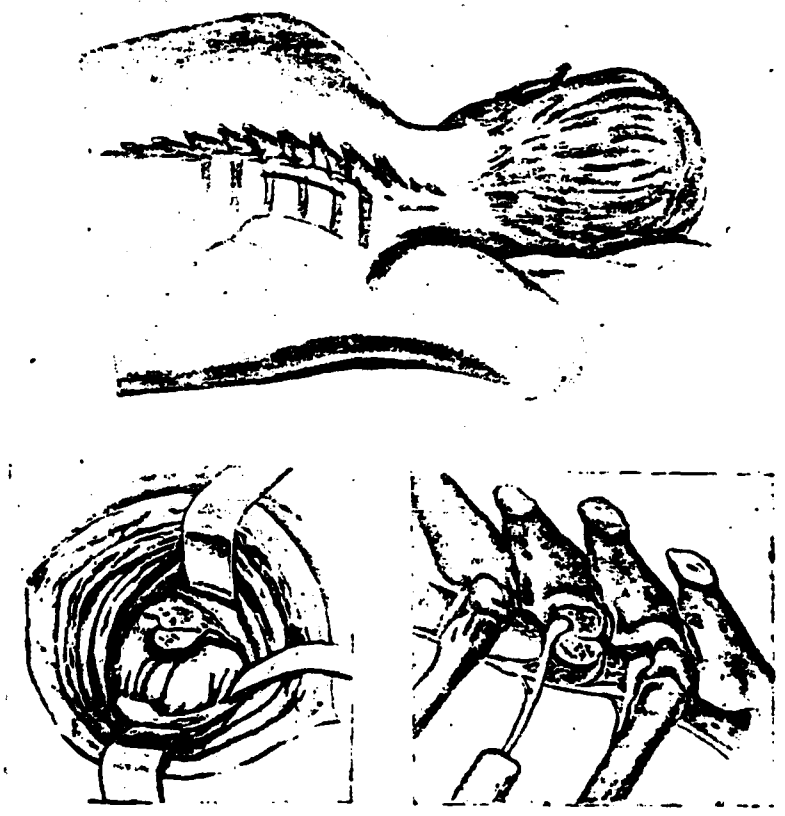


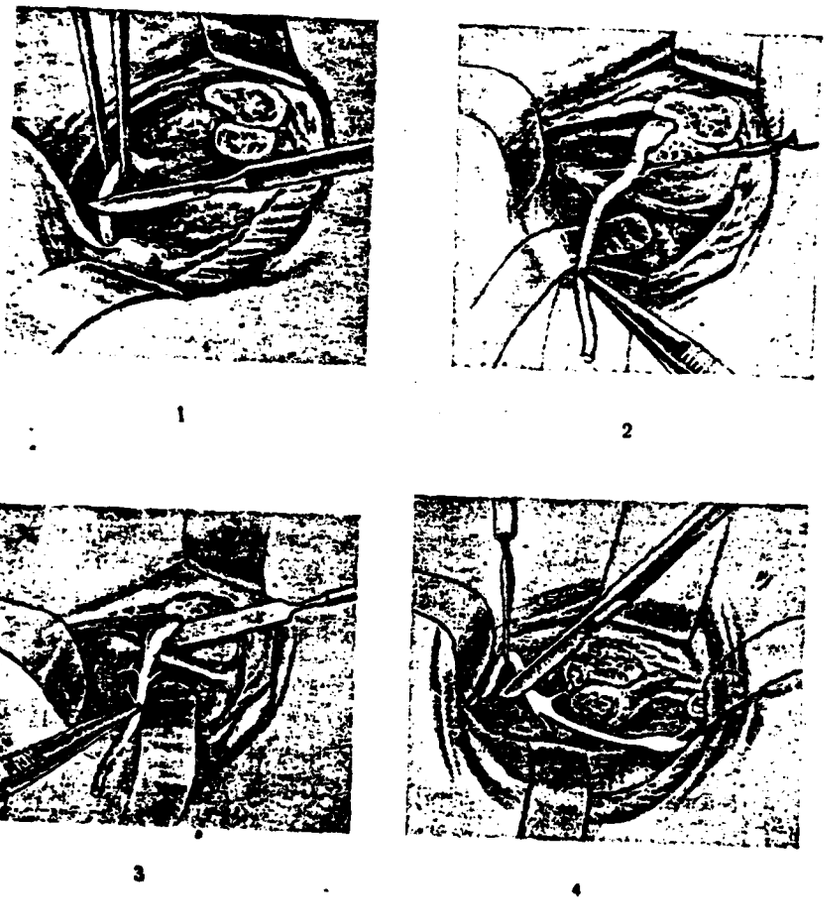
Fig. 157. Separate stages of surgical access to the sympathetic ganglia.

Second stage. A sharp scalpel is used to cut the articulatio costo-transversaria ligament of the III rib; a sharp straight chisel is first used to separate this articulation, and then the transverse process is chiseled off at its base. The subperiosteal resection of the III rib is performed taking all care to avoid injuring the pleura.

Third stage. Careful defibrillization of the remnants of the intercostal muscles is performed. This isolates the costovertebropleural sinus. Then the pleura is bluntly sectioned to the outside and the III and then also the II intercostal nerves along with the vessels of the same /426 name are isolated in the fatty tissue of the mediastinum.

Fourth stage. A rounded "nerve" hook is used to grasp the diverging connective branches. By means of tinic pulling the sympathetic trunk with the third ganglion is isolated. Resection of this section of the trunk together with the connective branches is performed. The wound is sutured by later. The operation is performed under local anesthesia with the patient lying on his stomach or on his side. A cushion is placed under the chest (fig. 158).

With careful implementation of all the stages, the operation presents no difficulties. Injury of the pleura disrupts the planned course of the operation. In this case, fruitless efforts to suture the pleura should be avoided, and the opening should immediately be closed with a moist /427 tampon. Injury to the veins in the mediastinum also requires immediate tamponade due to the danger of air embolism.




/426

Fig. 158. Stages of sympathetic ganglion removal.

Periarterial sympathectomy of the femoral artery /427

First stage. A cutaneous incision is made along the course of the tailor's muscle 18-20 cm in length. The broad fascia of the thigh is dissected, and then the muscle fascia. The latter is bluntly retracted to the outside. The sharp method is used to open the perivascular sheath.

Second stage. With the aid of a thin needle, novocaine is introduced under the adventitia of the artery for an extent of 16-18 cm; thus its exfoliation is achieved. The adventitia is grasped with thumb forceps and cut with ophthalmic scissors along the entire extent indicated above.

Third stage. The margins of the adventitia are grasped with Pean's forceps; the adventitia is exfoliated with a pisiform *tampon* away from the femoral artery, its branches and branclets for an extent of 16 cm and removed in a single layer. All these manipulations are invariably accompanied sy sufficient desympathization of the femoral vein, as well as intersection of all the nerve branchlets leading to the vessels segmentally from the nerve trunks of the femoral nerve. Sutures are applied to the broad fascia and to the skin.

The desympathization of the brachial artery is performed according to the same methodology.

## CHAPTER VIII
## ORTHOPEDIC OPERATIONS WITH CONSEQUENCES OF PERIPHERAL NERVE INJURIES

With injury to one nerve or another, the longer the /428
tendon-muscle apparatus is in a state of rest, the more subject it is to various degenerative changes and therefore, of course, the basis for functional restoration even with proper regeneration of the nerve after the operation is reduced.

During this period, there is often time for great changes to take place also on the part of the joints in the paralyzed extremity. These changes may prove to be irreversible, and the nerve regeneration which later ensues cannot lead to complete restoration of the extremity's lost function. The character of complications and deformations resulting from peripheral nerve injuries varies.

During the years of the Great Patriotic War, comparatively few orthopedic operations were performed for the correction of defective positions of the extremities in cases of nerve damage. Thus, according to the materials for the development of illness histories it was established that orthopedic and corrective operations were used in 2.0% of firearms injuries to the peripheral nerves, primarily in injuries to the nerve trunks of the lower extremities, for example with injury to the leg nerves (10.7%).

Despite the high level of nerve damage diagnostics, surgical technique, application of complex treatment for the injuries to the peripheral nervous system before and after

the operation, in a number of cases corrective surgery was required to restore the functions of the extremity.

The physiological conductivity of the damaged nerve after the operation often set in after very prolonged periods -- 1-1½ - 2 years. The restoration of sensation and movement took place non-uniformly.

During this period, the tendon-muscle apparatus, being in a state of rest and paralysis with injury to one or another nerve, was subjected to various secondary changes. The interaction between the paralyzed and non-paralyzed muscles was disrupted.

Often, changes in the joints of the paralyzed extremity also took place within this same period. These changes often proved to be irreversible on the part of the muscular apparatus as well as on the part of the joints.

All the consequences of peripheral nerve injuries which were observed according to the materials for the development of illness histories may be divided into two groups: 1) accompanied by loss of motor and sensory functions of the extremity, but not complicated by deformations; 2) complicated by deformations of the extremities resulting from changes in the tendon-muscle and ligament apparatus.

Various deformations developed as a result of injuries /429
to the peripheral nerves. Thus, for example, in injury to the sciatic nerve, a hanging foot was formed, partially in the position of pes equinus varus; active mobility in the talocrural articulation and in the metacarpo-phalangeal articulations was absent; a contracture of the toes was

formed, along with ulcers which would not heal. With injury to the fibular nerve, as a rule, the hanging foot was also observed, and active movements in the foot and talocrural articulation were also absent. Especially significant changes were noted on the part of the hand and fingers with injuries to the radial nerve, the ulnar and median nerves; clinically there was a manifestation of a limp hand, contractures of the hand and fingers, limited mobility of the fingers, hand, pronation and supination.

For purposes of retaining the static and functional interrelations between the muscles and prophylaxis of various deformations in the treatment of peripheral nerve injuries, plaster bandages and orthopedic apparata were used from the very beginning of the treatment.

For the same purpose, some authors proposed performing orthopedic tendon transplant operations without waiting for the results of surgical treatment of the injured nerve, but performing a simultaneous operation on the nerves (nerve suture) and on the tendons (plasty or tendon transplant). We can hardly agree with this proposal. The application of orthopedic operations, particularly tendon transplants, cannot exclude after the operation the possibility of prescribing apparata or footwear for long-term periods in order to assure complete restoration of the function of the injured extremity. The experience of the Central Institute of Traumatology and Orthopedics convinces us that in performing operations simultaneously on the nerve and on the tendons, subsequently in restoring the nerve a repeated operation is required on the tendons, i.e., transplant of the tendon to its former place.

The orthopedic apparata which are prescribed in peripheral nerve injuries of the upper and lower extremity before the operation as well as after the operation have the purpose of holding the hand and fingers, as well as the foot, in a functionally useful position, of exercising the retained muscles, and of facilitating by means of new reflexes the implementation of a new function on the part of the transplanted muscles.

At the 6-th Plenum of the Scientific Medical Soviet, attention was directed toward the importance of timely and proper splinting of the extremity in cases of nerve trunk injuries.

Various types of orthopedic apparata were used for the upper as well as for the lower extremity. All these apparata may be divided into two groups: a) simple apparata which retain only the hand, or apparata retaining the primary phalanges of the II, III and IV fingers and which abduct the thumb; b) apparata with an elastic pull in the form of a spring or rubber band.

With paralysis of the radial nerve and with the limp hand, a wire splint was used which ran along the forearm. The peripheral end of the splint was a closed arch which was bent upward to give the hand the position of hyperextension. The apparatus was secured on the forearm with two cuffs, of which one passed along the dorsal surface of the forearm, and the other -- along the palmar surface. This achieved good fixation of the apparatus (fig. 159).

The most rational and the most often used was the apparatus which consisted of a leather case for the forearm

and the hand. Attached to the case in the area of the radio- /430
carpal articulation on both sides were two arched splints located on the dorsal surface of the hand. Extension of the hand and fingers is done by means of rubber bands secured on leather rings and placed over the base of the primary phalanges.

With the aid of such an apparatus, extension of the primary phalanges and the hand was achieved. The force of extension of the fingers depended on the degree of tension and elasticity of the rubber bands (fig. 160).

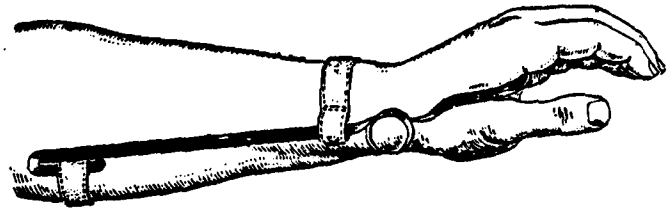


Fig. 159. Wire splint used in treating paralysis of the radial nerve.

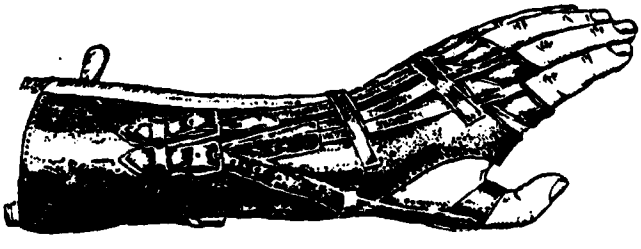


Fig. 160. Apparatus used for fixation of the radiocarpal articulation with injury to the radial nerve.

With injury to the nerves of the lower extremity -- the sciatic nerve, the fibular -- orthopedic apparata or footwear were used, depending on the functional condition of the extremity (fig. 161).

Disruption in sensitivity on the part of the foot, as well as various trophic disorders hindered the use of orthopedic apparata or footwear. In these cases, the preparation of individual devices and constant observation of the injured extremity as well as of the orthopedic devices was necessary.

The presence of various functional disorders which developed with nerve injuries made it necessary in a number of cases to seek other means of combatting these disorders. Various orthopedic interventions have been used.

Orthopedic operations pursued the following goals: 1) the restoration of the most favorable static conditions for the injured extremity; 2) the replacement of functions of the afflicted muscles by functions of unafflicted, healthy muscles.

Of the orthopedic interventions with peripheral nerve injuries, tendon transplants were generally used, and only in individual cases arthrodesis or arthrolysis. Tendon transplants were used with injury to the radial, fibular nerve and comparatively rarely -- in cases of paralysis of the /431
ulnar and median nerve. Arthrodesis was resorted to only in those cases when the tendon transplant operation could not give effective results. For example, with injury to the brachial plexus -- the operation of arthrodesis of the humeral articulation; with injury to the sciatic nerve, with significant injuries to the crus muscles and their irreversi-

bility -- the operation of arthrodesis of the talocrural articulation.

Fig. 161. Orthopedic footwear used with nerve trunk injuries of the lower extremities.

The materials on the literary data dealing with performed operations on tendon transplant and articulatory arthrodesis with peripheral nerve injuries are scant. There is especially little information available on the long-term results of tendon transplant operations in cases of nerve injury. The materials of hospital reports contain individual indications as to the application of these operations, but as yet there are no broad generalized data on their effectiveness.

The most widespread with injury to the radial nerve were operations consisting of the following moments:

a) muscle tendon - radial flexor of the hand was transplanted to the tendon of the short extensor of the thumb;

b) tendon of the ulnar flexor of the hand was transplanted to the tendon of the common digital flexor;

c) tenodesis of the short radial extensor of the hand was performed.

In 1908, A. V. Tikhanovich first performed plastic surgery with radial nerve injury. The data on this operation were presented at the VIII Congress of Russian Surgeons in 1908 and published in 1913. At the XVI Congress of Surgeons in 1925, A. V. Tikhanovich again spoke out on this question, redommending that simultaneously with suture of the radial nerve, the radial flexor of the hand should be transplanted to the common digital extensor and that the long and short tendon of the thumb extensors be shortened.

This operation was performed by the author on 22 patients. /432 In his subsequent works during the period of the Great Patriotic War, he reports on 60 cases of muscle plasty. Works are also known dealing with the application of muscle transplant with nerve injuries (Yu. Yu. Dzhanelidzye, E. Yu. Osten-Sakena, G. Ya. Epshteyn, V. Ya. Shlapoberskiy, V. D. Chaklin and others).

In tendon transplant operations, it is necessary to adhere to conditions which, if overlooked, will reduce the positive results of the operation. These conditions may be formulated as follows:

1. Determining the functional condition of the muscles of injured nerves, as well as those which will be transplanted for replacement of afflicted ones.

To determine the functional capability and degree of injury to the neuromuscular apparatus, we may recommend the

application of chronaxymetry and the recording of muscle electrical currents. On the basis of the electrophysiological studies, three pathophysiological conditions of the neuro-muscular apparatus are distinguished:

a) Muscle paralysis in which the absence of muscle response to intensive electrical stimuli and the absence of biocurrents are noted.

b) Sharp reduction in the physiological effectiveness of the muscle. A sharp increase is noted in the value of the rheobase and of chronaxy. Here the muscle biocurrents are altered in the direction of reducing the number of oscillations (up to 16 instead of 52 per second) and their amplitude. The load on the muscles, according to the data of biocurrents, causes a very rapid fatigue (within a period of 3-5 minutes) with reduction in the amplitude and the frequency of oscillations and with their disappearance. Subsequent treatment measures with similar conditions do not improve the function of the muscles, according to biocurrent data.

c) A moderate reduction in the physiological activity of the muscle with a sharp reduction in its function. Slight changes in the rheobase and chronaxy waves are noted. The muscle biocurrents are not altered as compared with the healthy muscle, and only prolonged (over a period of 20-30 minutes or more) load of 10 kg indicates a reduction in the frequency and amplitude of the oscillations.

The determination of the three pathological muscle conditions makes it possible to establish the degree of muscle damage, the extent of this damage, and to present

more precise indicators for transplant of the physiologically best preserved muscle.

2. The complete correction of existing deformations and contractures on the part of the extremity.

Tendon transplants for purposes of correcting deformations are not used.

Therapeutic means as well as surgical are used to correct deformations: redressation, by-stage plaster bandages, special devices, and physical treatment methods.

With unsuccessful therapeutic measures, particularly in cases of stable contractures, tenotomy, tenoplasty, fasciotomy, myotomy, wedge bone resection and osteotomy were prescribed.

3. It is possible to transplant muscles which are related in a functional sense to those being replaced. The closer the function of the healthy transplanted and the paralyzed muscle, the better the result and the more rapidly it will become apparent. However, success occurs also when, instead of a muscle related in function, a muscle which is remote in position and in function, and even a muscle antagonist is used. This is explained by the fact that the function of the muscle is manifested not only by the motor act, but also by the stabilizing act. Muscles which are antagonists during movement become synergetic during stabilization. For example, when the flexors of the radiocarpal articulation are transplanted to the dorsal surface of the hand in order /433 to perform the function of the extensors, they perform a function which is not foreign to them, since both these muscle groups, the flexors as well as the extensors, act simultaneously

as stabilizers of the radiocarpal articulation.

With the aid of kinesotherapy and exercise therapy, the muscles take on functions which are not characteristic to them.

4. The transplanted muscle must be correspondingly strong to ensure the required action. For example, if in paralysis of the digital flexors only the long palmar muscle is transplanted, this will not give normal restoration of movement to the fingers. On the contrary, if a stronger tendon is transplanted as compared with the one it is replacing, deformation may result.

5. Whenever possible, tendons are replaced along a straight line so that the tendon may act with full force at the point of its attachment. Usually the tendons are placed according to the principle of direct application of force.

6. Suturing the tendon is done with corresponding tension. With too much tension, the muscle will not act and the suture may come apart. With weak tension, great muscle force is necessary to ensure the effectiveness of the action.

7. The attachment of the tendons is given great significance. A number of authors recommend performing tendon attachment to the bone or the periosteum.

With operations on the lower extremity, it is recommended that tendons be attached to the bone and the periosteum, and in operations on the upper extremity -- to the tendon.

8. In the post-operative period it is necessary to use physical treatment methods, special exercises, light massage, and often -- to prescribe special orthopedic devices or orthopedic footwear.

In the Central Institute of Traumatology and Orthopedics of the USSR Ministry of Public Health during the years of the Great Patriotic War and in the post-war years, 363 patients with consequences of peripheral nerve injuries were treated. Of these, 255 patients were subjected to operative intervention. 250 Patients were given plasty operations for transplant of various muscles, depending on the injured nerve, and only 5 patients with injury to the sciatic nerve were given arthrodesis of the talocrural articulation.

Several different variants have been proposed for transplanting tendons in cases of paralysis of the radial nerve. Usually the tendons of the flexors of the hand were transplanted to the tendons of the digital flexors.

The ulnar and radial flexor of the hand was transplanted to tendons of the common digital extensor, the short extensor of the thumb, and the long muscle abducting the thumb. According to the method of Shtoffel', the tendons of the radial flexor of the hand were transplanted to the tendons of the short radial extensor of the hand, the tendons of the ulnar flexor of the hand -- to the tendons of the common digital extensor and the extensor of the thumb, and the tendons of the superficial digital flexor -- to the tendons of the short extensor of the thumb and the long muscle abducting the thumb.

Yu. Yu. Dzhanelidze proposed transplanting the tendons of the radial flexor of the hand to the tendons of the common digital extensor, the tendons of the ulnar flexor of the hand -- to the tendons of the short extensor of the thumb and the long muscle abducting the thumb (crossing /434 of the tendons is performed).

In the practice of treatment institutions recently, the method proposed by Yu. Yu. Dzhanelidzye is becoming most widespread. A clear confirmation of the effectiveness of this intervention may be the following observation.

Patient S. Injury to the radial nerve. Wounded in 1944. Complaints of inability to use the right hand. Atrophy of the muscles of the right brachium and forearm; the right hand is limp; the fingers are bent at the primary phalanges; extension of the hand and fingers, pronation and supination are impossible; active movements in the right elbow joint are limited; passive movements are possible in all directions; hypesthesia of the dorsal surface of the right hand in the zone of innervation of the radial nerve.

The operation: the muscle tendons of the radial flexor of the hand and the ulnar flexor of the hand were isolated and cut. The tendons of these muscles were led subcutaneously into the incision on the dorsal surface of the forearm. The tendons of the flexors of the II, III and IV fingers were isolated. With maximal flexion of the fingers, a loop was made on the tendons, to which the tendon of the ulnar flexor of the hand was sutured, the tendon of the long and short extensor of the thumb and the muscle tendons abducting the thumb were isolated. A loop was also made along the extent of these tendons, to which the tendon of the ulnar flexor of the hand is sutured. Sutures were applied to the skin and a plaster bandage was applied. After 2 weeks, light active exercise, physiotherapy and light massage were applied. After 2 months the patient was discharged with a good functional condition of the hand and a supporting splint. A year later the functional condition continued to remain fully satisfactory; The hand is used without a splint.

With injury to the sciatic nerve, orthopedic operations for correcting a defective position of the foot were made much less frequently than with injuries to the nerves of the upper extremity. This is explained by the fact that in injury of the sciatic nerve, vasomotor, secretory and trophic disorders develop very early on the crus and on the foot which are very difficult to combat. With complete injury of the sciatic nerve, muscle transplant is not indicated. Only intervention on the Achilles tendon may be recommended -- tenotomy, tenoplasty and prescription of orthopedic devices. The following observations may serve as an illustration.

Patient T. Injury to the right sciatic nerve; unhealing ulcer. Wounded in 1944. In 1945 an operation of nerve suture application to the sciatic nerve was performed -- no effect was noted.

In 1945 another operation was performed on the sciatic nerve. In 1947 an ulcer appeared on the foot; the foot was deformed; movement in the talocrural articulation and in the toes was absent. The right foot was limp. There was anesthesia on the posterior external surface of the crus and the foot; the Achilles tendon reflexes were absent. Muscle contraction in the study of chronaxy above and below the point of the operation on the sciatic nerve was absent. Capillaroscopy of the right foot revealed that the capillaries are acutely contracted; the background is light pink; the venous-arterial branches are shortened. The number of capillaries at the sympathetic margin is 20; blood flow could not be determined. There was a picture of vascular spasm, more sharply expressed on the front side. Another operation was performed in 1949. The old post-operative scar was excised, the nerve ends exposed, complete severance of the sciatic nerve was established; neuromas were present; resection of the nerve endings was performed; nerve suture was performed, as well as redressement of the foot and tentomy of the Achilles tendon. The post-operative course was smooth. The movement of the foot was not restored. After 3 months an orthopedic device was prescribed, with the aid of which the patient is able to use the extremity.

Patient N. Paralysis of the right sciatic nerve; false hip joint. Wounded in 1943; twice subjected to

operation due to sciatic nerve injury. Pains in the right foot; acute muscle atrophy of the right crus and thigh. Movements in the foot and toes are absent; contracture of the toes and foot; complete anesthesia of the toes and foot; unhealing fistula at the point of the false joint. Upon the persistent request of the patient, amputation of the thigh was performed.

With isolated injury of the fibular nerve, muscle transplant operations were widely used. In these cases usually operations of Achilles tendon tenotomy were performed, the /435 anterior tibial muscle was transplanted to the external part of the foot to the fifth metatarsal bone.

Aside from the operation indicated above, tenodeses were used in cases of paralysis of the fibular nerve. The operation consisted of first performing tenotomy of the Achilles tendon, then drilling 1 or 2 canals in the tibia, intersecting the tendon of the anterior tibial muscle and the long extensor of the toes at the point of transition to muscle. The peripheral ends of the severed tendons were passed through the canals and sutured with the central segment of these tendons. The foot was given a central position.

The long-term results of operations with transplant of the anterior tibial muscle as well as tenodeses were observed over a period of 3-5 years. The function after the operations was good in all cases.

Thus:

1. With injury of the peripheral nerves and unsuccessful surgical treatment it is necessary to recommend corrective orthopedic surgery.

2. Of the corrective orthopedic operations, the most

applicable are certain tendon transplants with injury of the fibular nerve and the radial nerve. With injuries to the ulnar, median and sciatic nerve, orthopedic devices were usually prescribed.

3. Before performing orthopedic operations, it was necessary to correct the existing deformations by means of by-stage redressement.

4. Arthrodesis operations in cases of paralysis of the extremities resulting from injuries to the peripheral nerves found no application.

## CHAPTER IX

## RESIDUAL MANIFESTATIONS OF PERIPHERAL NERVE INJURIES AND THE METHODOLOGY OF TREATING THEM IN THE LATER PERIOD

The study of the clinical picture and the development of /436
a methodology of treatment for peripheral nerve injuries in the later period are of significant importance. These later conditions (complications) are characteristic for wounded patients in whom 6-7 years after the firearms injury to the peripheral nerves restoration of function is not observed at all or insufficiently manifested. All such wounded may be divided into two basic groups.

The first group is characterized by those complications which are based on the loss of conductivity in the nerve trunk. This type of later residual manifestations in a clinical sense differs little from the corresponding residual conditions at earlier periods from the moment of injury. These conditions, as we well know, are characterized by flaccid paralysis or paresis and by the loss of sensation to a greater or lesser degree corresponding to the zone of innervation of the injured nerve, its individual characteristics, and the level of injury. As a rule, electrophysiologically there is a deeper degree of the degeneration reaction.

The most varied types and forms of loss in conductivity of one nerve trunk or another have been repeatedly described in numerous works and manuals and do not require additional description. Also it is necessary to note that the accepted classifications of such disruptions in the form of individual "syndromes" are to a significant degree artificial, and often

even mechanistic.

However, there are a number of reasons which force us to pause on this group of wounded patients in whom the basis of the residual condition in the later periods after nerve trunk trauma is the manifestation of loss in the conductivity of the injured nerve. These, so to speak, "pure", cases which are uncomplicated by secondary processes, are far from the only type occurring in the later periods. It is possible that most such patients adapt to their defect. This, undoubtedly, is the result of the high level at which the organization of labor of invalids from the Great Patriotic War stands in the USSR.

We must focus our attention on this "uncomplicated" group of residual conditions in order to stress once again the necessity of the earliest possible and systematic treatment of patients with peripheral nerve injuries. Such an uncomplicated condition in the later periods, as a rule, is noted only in patients subjected at an early time to regular treatment, and not varying from case to case.

In practice, with uncomplicated conditions even in the /437
latest periods, the basic measures are directed toward the restoration of conductivity of the afflicted nerve. However, in later periods the conditions for this are significantly different. The experience accumulated in the period of the Great Patriotic War has greatly changed former ideas regarding the treatment of firearms injuries to the peripheral nerves and has made it possible to work out a rather clear line of behavior. However, this cannot be noted for later periods. The time elapsed since the war and the observations which have been accumulated present new problems. Already now we

we must begin preparations for considering the long-term results after operative interventions performed at later periods after the moment of injury with consideration of those specifics which are in direct connection with the factor of time. As an example it is sufficient to indicate that up to this time there are no data which would indicate the possibility of regenerative processes depending on the degree of the degeneration reaction. What is the limit of expediency in trying to restore nerve conductivity depending on the time elapsed since the injury? What is the morphological substratum necessary in later periods for the successful course of regenerative processes in the nerve? There are many such moments which are by far not yet clear. For purposes of solving some of these questions, a study is being conducted at the Institute of Neurosurgery imeni Academik N. N. Burdenko on the reasons which hinder the regeneration processes after the earlier performed operative interventions on the nerves.

Observations of recent years show that the basic reason which brings most patients to us in later periods from the time of injury consists not of manifestations of loss in the conductivity of the injured nerve, but in secondary processes which complicate the injury of the nerve. This will be discussed in the description of the second group of later residual conditions. These are the patients comprising the second group.

Even earlier M. G. Ignatov stressed that, in evaluating the condition with peripheral nerve injuries, it is necessary to start from a description of the disruption in the function of the extremity as a whole, and not only from the condition of the injured nerve, which should be examined only as one of the links in a single functional system (the extremity) as a

whole. The character and degree of disruption in the conductivity of the injured nerve, undoubtedly, are rather significant. However, the range of significance of this factor is rather varied and fluctuates within very wide margins. The degree of disruption in the function of the extremity often depends here not so much on the disruption in the conductivity of the injured nerve as on the secondary processes complicating the injury.

These later conditions differ significantly from the earlier conditions primarily in the respect that in the former cases the character and degree of the nerve injury among the reasons conditioning the disruption in the function of the extremity are often put off into the distant background. At the same time, secondary processes which complicate the nerve injury at earlier periods, as a result of their development, take on a new qualitative significance in later periods. An analysis of the reasons for the disruption in the function of the extremity at later periods indicates that injury to the nerve trunk itself, which plays a basic or leading role directly after the injury is sustained and in earlier residual conditions, loses this importance to a significant degree in the later periods. It is sufficient to indicate, for example, the cases of injuries to the ulnar nerve. It is well known that even total severance of this nerve on the forearm at earlier periods leads to a rather insignificant disruption in the function of the hand. How- /438
the subsequent atrophy of the small muscles of the hand which later ensues leads to a defective (the so-called claw-shaped) position of the fingers, while the contracture which develops in later periods sharply limits the function not only of the IV and V fingers, but also of the entire hand, i.e., practically the entire hand.

We must pause on the basic reasons for the disruption in the function of the extremity in later periods in patients with peripheral nerve injury who do not show any noticeable effect from the treatment performed earlier.

The division of firearms injuries to the nerves separately into motor, sensory and vegetative-trophic disruptions is purely mechanistic, since the point is not in their difference, but rather in their singularity, their connection, their interaction and development throughout the course of the entire period of illness. Therefore an analysis of later conditions after peripheral nerve injuries should be begun with an examination of contractures, rigidity and defective positions of the extremity, and not with a presentation of the locomotory disorders, as is usually done. In the later periods, motor disorders are determined primarily not by paralysis or paresis of one set or muscles or another, but specifically by these second conditions which complicate the nerve injury. Qualitatively these conditions are completely different than they are in earlier periods from the moment of injury.

Contractures in later periods also differ significantly from contractures in these patients at earlier times from the moment of injury. This relates primarily to the group of so-called reflex contractures, whose essence, pathogenesis and treatment methods were developed in the years of the Great Patriotic War by our country's authors (S. N. Davidenkov, A. M. Grinshteyn, A. Yu. Sozon-Yaroshevich and many others). However, it is necessary to stress that the developed methods of treating these contractures cannot be used in later periods from the moment of injury. We may express some doubt as to whether, after the passage of 5-7 or more years from the moment of injury, there is at all a type of contracture which

may be called "reflex". In actuality, in studying such patients at later times after the injury, there are no data which could indicate that the same reflex (central) mechanism take place at these times which earlier conditioned the formation of the contracture. Moreover, not one of the developed methods of treating reflex contractures, which are so effective in fresher cases, as a rule has any effect on the condition of the contracture at later periods. Neither novocaine block of the ganglia of the sympathetic nervous system, nor elimination of the focus of irritation at the point of injury of the nerve trunk, nor sympathectomy have any effect on the condition of the contracture during the later period.

The reflex mechanisms which have an undoubted significance in earlier periods lose their actuality with time. In the later periods the most significant, basic and, unfortunately, usually irreversible, are the secondary atrophic processes, fibrose degeneration and retraction of the individual muscles, and more often the muscle groups. In such cases, electrodiagnosis indicates the complete reaction of degeneration, and often -- also the complete absence of excitability of the muscle itself.

Thus, in the process of development, the role of the reflex mechanisms, the role of the damaged nerve recedes into the background, yielding the primary place among the reasons conditioning the disruption in the function of the extremity to the affliction of the locomotory apparatus itself -- injury to the muscles.

The forms of defective positions of the extremity conditioned by secondary afflictions of the motor apparatus resulting from atrophic and fibrose processes are rather varied. /439

Without touching upon all the symptomatics of the various disruptions, we will note only the following significant traits: 1) these processes are most expressed in the distal regions of the extremity; 2) the degree of disruption in the function of the extremity goes far beyond the bounds of the zone of distribution of the injured nerve, encompassing equally and differing only in quantity the function of the synergists as well as the antagonists.

It is necessary to note that in a number of cases the integrity of the antagonists to a considerable degree determines the defective position of the extremity, increasing the degree of disruption in the function of the extremity as a whole. This is observed, for example, in the later condition after injury to the fibular nerve or in cases of injury to the sciatic nerve, when in the process of regeneration only one tibial portion was restored. Here is what was often noted: a more or less fixed condition of the foot in the position of pes equinus and the I digit -- in the position of plantar flexion. This position of the foot does not permit the practical use of footwear, while the flexed I digit causes great inconvenience in walking.

The defective positions of the extremity in the later periods after firearms injuries to the peripheral nerves are rather varied. A significant number of them may be eliminated by neurosurgical interventions and require special orthopedic treatment.

Among the reasons which determine disruption of the motor function in later periods, undoubted significance must be given to vascular and vegetative-trophic factors, and particularly their character and development in the preceding periods. It is specifically the character and the development

of these processes that often determine in the later stages the degree of disruption not only in the motor function, but also in the function of the extremity as a whole.

Most significant is the circumstance that most vascular and vegetative-trophic disruptions, which are at earlier periods reversible to a significant degree, in the later periods lead to stable and often irreversible changes in the support-motor apparatus. Here we must note that the reflex mechanisms, which at earlier periods are basic in the genesis of the vascular and vegetative-trophic disruptions,are absent in later periods or have only a small significance.

It is interesting that of the considerable number of patients seen in the later periods after the injury, not in a single case was the primary complaint the absense of sensation. Of the sensitivity disorders, often the main ones in the later periods were only pains (and not loss of sensation). However, it would be incorrect to diminish the role of sensitivity disruption. Examining the various manifestations not abstractly, but in close connection with the others, it is easy to be convinced that even so-called "pure" loss of sensation (without pain) has a significant importance among the reasons conditioning the disruption in the function of the extremity during later periods after the nerve injury. From the works of the Institute for Neurosurgery imeni Academik N. N. Burdenko it is evident what a significant importance is played by the factor of loss of sensation among the other reasons leading to the development of trophic ulcers which often afflict the extremity as a whole.

Pain in the earliest, as well as in the latest periods after the nerve injury is often the basic reason for the disruption in the function of the extremity as a whole, re-

gardless of the degree of nerve trunk injury. /440

There was not a single report of causalgic pains after several years since the injury had elapsed.

The most frequent and persistent are phantom pains. Here it is most characteristic that, with the existence of these pains within the course of several years, they evidently become purely central. The role of local factors (neuromas, scars etc.), as well as reflex mechanisms evidently loses its significance. Speaking in favor of this is the fact that neither the removal of neuromas and scars, nor sympathectomy, nor any other interventions on the peripheral paths do not usually give any positive effect, which is often achieved by these operations in earlier periods.

Rather frequent and most characteristic for later periods are vascular pains and pains from incomplete regeneration.

Vascular pains, or as they are usually called -- ischemic pains -- are generally known. These are dull, aching, often difficult to localize pains, usually of varying intensity, often with remissions. It is notable that in the later periods these pains become more stable and remission, as a rule, is absent. The reason for this is evidently the fact that the functional condition of the vessels which determines the insufficiency of blood supply during early periods is subsequently replaced by more gross organic changes. Also characteristic is local soreness along the course of the nerve trunks analogous to that which is observed in the later stages of obliterating endarteritis, improperly called "ischemic neuritis".

It is difficult to determine the line of treatment in regard to these pains. Usually the condition of the extremity is such that one can hardly expect success in efforts to restore conductivity of the afflicted nerve. It is known that often with these pains a good effect is given by physiotherapy. However, we must think that in such cases before conservative treatment it is expedient to perform sympathectomy for purposes of greater utilization of the compensatory capabilities of the vascular system.

Pains with incomplete regeneration differ little from pains observed at earlier times. These pains, which are usually localized in the zone of the afflicted nerve, are clearly of a protopathic character. However, the course of treatment, depending on how long ago the the injury was sustained, is different. If in earlier periods these pains may be an indication of the growth of nerve fibers and may indicate incomplete regeneration requiring only improvement, in the later periods the situation is different. In the later periods we are already speaking not of incompleted regeneration, but of defective regeneration, which first of all requires intervention in the area of the nerve injury.

What, then, should be the course to follow in regard these complications of later conditions following firearms injuries?

In many such cases the basic problem consists of the maximal utilization of residual vunctional capacities of the injured extremity. Often the main role in this belongs not to the neurosurgeon, but to the orthopedist. In the surgery of firearms injuries to the peripheral nerves, both these specialties are closely related, regardless of the time elapsed since the injury. However, depending on the time

factor, the order of the sequence of orthopedic or neurosurgical interventions changes radically. If we discount those cases when restorative orthopedic interventions are /441 necessary in the area of the injury, which are performed at early periods usually together with intervention on the nerve, then the general sequence is basically as follows. In early periods, orthopedic operations whose goal is to correct the position of the extremity are done, as a rule, only after unsuccessful intervention on the nerve. Such operations in the interval periods, particularly in the presence of reflex contractures, should be performed only after preliminary intervention on the injured nerve or together with it, since in the presence of reflex disorders an orthopedic intervention alone cannot have much success if the reflex moments are not eliminated by means of intervention on the afflicted nerve. The case is entirely different in the latest periods, when secondary dystrophic processes in the support-motor apparatus cannot be eliminated by any intervention on the nerve.

With sharply expressed atrophy, sometimes gross fibrose degeneration of the muscles themselfes, in later periods the expedience of interventions on the nerves is always doubtful. However, such intervention even in later periods is undoubtedly indicated if the conductivity of the injured nerve is even partially retained.

In later periods we had occasion to observe cases where the clinical picture indicated complete disruption of nerve conductivity, while a more detailed examination indicated the confirmed presence of nerve regeneration to one degree or another. As a rule, studies have indicated the insufficiency of peripheral blood supply. In two cases, active

movements appeared in such patients in the very first days following sympathectomy.

There are very many reasons for disruption in the function of the extremity during the later periods after the injury is sustained. The question of expediency of some interventions or others at this time, especially in neglected, complicated cases,has been studied very little. This question requires additional study, beginning primarily with the study of the actual possibility of the regenerative processes depending on the time factor.

What constitutes the reason for the development of the most severe complications after firearms-inflicted nerve injuries?

Basically, there are two reasons for this: 1) insufficiently systematic and regular performance of physiotherapy and mechanotherapy during the earlier periods and 2) low surgical activity. The overwhelming majority of such patients was not subjected to operation on the nerve at all. Some of them were operated, but no favorable effect was noted over a number of years. The observations indicate the unconditional necessity of repeated operation.

The organization of this type of aid must be review on the basis of the data obtained as a result of the treatment of materials from illness histories of firearms injuries to the peripheral nerves during the period of the Great Patriotic War.

## CHAPTER X

## LONG-TERM RESULTS OF SURGICAL TREATMENT OF FIREARMS INFLICTED INJURIES TO THE PERIPHERAL NERVES

The great success achieved in treating firearms injuries /442
to the peripheral nerves in the Great Patriotic War were a result of the highly developed organization of the Soviet Army's medical evacuation service which brought specialized types of aid directly up to the combat lines, as well as of the specifics of the rapid development and growth of military field neurosurgery, which provided operative intervention at early periods, thereby considerably expanding the indications for surgery in nerve injuries.

We can only give a proper evaluation of treatment in cases of peripheral nerve injuries by studying the long-term outcomes, which determine the true effectiveness of the conducted therapy.

The materials for the development of illness histories were used to evaluate the long-term results of surgical treatment in firearms injuries to the peripheral nerves. An evaluation of the effectiveness of operative intervention was performed on the basis of reviewing questionnaires sent to the patients. Also, the questionnaires were most cases filled out on site by the physicians, which made it possible to compare the dynamics of functional disruptions. Aside from this, a study of results was conducted according to the data obtained in studying wounded patients called to the polyclinic of the Institute for Neurosurgery imeni Academik N. N. Burdenko,

as well as by studying numerous wounded patients in the institute's hospital. Responses to questionnaires suitable for use were obtained from 2,016 wounded patients with a period of observation of up to 7 years.

The materials of personal observations played an important significance in evaluating the long-term results of surgical treatment in cases of firearms wounds to the peripheral nerves. Out of 3,207 patients who had been operated, information concerning the outcome of the treatment was received from 631 patients (B. G. Yegorov, M. A. Nikitin).

Materials obtained from individual surgeons (A. A. Dikova, P. A. Kartashev, P. A. Kovalenko, A. Yu. Sozon-Yaroshevich, D. G. Shefer, K. P. Chikovani) were used in evaluating the results, amounting to a total of 1,237 cases.

Along with this, data on the outcomes of surgical treatment of firearms wounds to the peripheral nerves published by individual authors and comprising a total of 1,155 cases were considered.

Thus, the basis for evaluation of long-term results of surgical treatment in peripheral nerve injuries was the observation of 5,039 wounded patients studied at various times /443 after the operation, primarily from 3 to 7 years.

One of the most difficult problems in organizing the computation of the results of treatment in peripheral nerve injuries is the outcome criterion. Much time elapsed after the First World War before analyses of the results of operative and conservative treatment of nerve injuries began to appear in print. The data, which were often based on relatively

broad material, indicated a significant number of good outcomes, but with deeper study it was easy to see that the final evaluation was subjective and that these data were statistically imprecise. The evaluation of this material was performed only according to two indicators, which testified to the success or failure of the operatire treatment. Among the successful cases were those in which even insignificant restoration of active movement was noted.

In studying the material of illness histories and published data of numerous authors for the period of the Great Patriotic War, particularly evident are the results after the nerve suture operation or neurolysis. In the application of a nerve suture during the operation, anatomical severance was established, while in neurolysis the presence of only a physiological severance was assumed with absence of anatomical data on the condition of the nerve trunk. Therefore, all the cases in which after neurolysis or conservative treatment the function was not restored cannot yet be evaluated as unsuccessful. Such results must be explained by incorrectly developed indicators. An analysis of the development of materials of illness histories gives us a basis to expand the indicators for operative intervention. In cases where neurolysis was unsuccessful, nerve suture application may prove to be successful. In cases where conservative therapy was unsuccessful, neurolysis or suture may be useful, depending on what will be discovered on the operating table.

Numerous authors made attempts to evaluate the outcome of an operation very early, basing their ideas on experimental data on the regularity of nerve trunk regeneration.

It must, however, be noted that the regularity of axon

growth under experimental conditions far from corresponds to the conditions of nerve function restoration after an operation.

Nerve regeneration after suture application due to fire-arms injury also depends on a number of reasons: on the character of injury to the nerve itself, on accompanying injuries to other tissues of the extremities -- the bones, muscles and vessels. Fig. 162 illustrates that with combined injury to the nerve trunks and soft tissues there are more favorable outcomes than with the simultaneous injury to the nerve trunks, bones and vessels.

The degree of functional restoration depends to a considerable degree on the character of wound infection, its development, and especially the time elapsed from the moment of injury to the operation, as well as on the methodology of conservative treatment. The curves in fig. 163 reflect the character of functional restoration depending on the operative interventions performed at various times after the injury. They show that the best functional restoration was noted after operations performed in the first months (up to three) after the injury was sustained. The more time elapsed from the moment of injury to the surgical intervention, the less effective were the results and the percentage of fruitless operations progressively grew, reaching it highest numbers at a time in excess of 2 years after the injury.

Finally, a huge significance for the outcomes of operative interventions is played by proper operative technique, method of access and thoroughness in treating the nerve trunk, the methodology of suture application, accompanying injury to other tissues, their treatment, and finally the method of protecting the nerve from scars, subsequent treatment, etc. /445

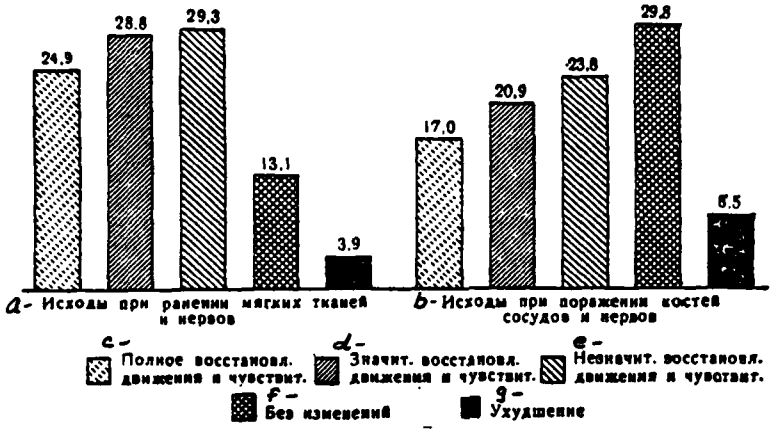



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Fig. 162. The long-term results of surgical treatment in firearms wounds to the peripheral nerves in combination with injuries to the soft tissues, bones and vessels.

a - Outcomes with injury to the soft tissues and nerves; b - Outcomes with injury to the bones, vessels and nerves; c - Total restoration of movement and sensation; d - Significant restoration of movement and sensation; e - Insignificant restoration of movement and sensation; f - No change; g - Deterioration.

The conclusions on the results of operative treatment /445 are based on the data from the study of materials for the development of illness histories, medical reports and the personal observations of a number of authors.

The materials from the study of long-term results show that complete or partial restoration in the conductivity of the severed nerve was noted in a huge percentage of cases. In these cases, the more complete was the organization of treatment, the better results were noted after surgery on the individual nerves.

One of the very important questions must be considered the evaluation of results from the standpoint of the proper consideration of time for the restoration of the lost function.

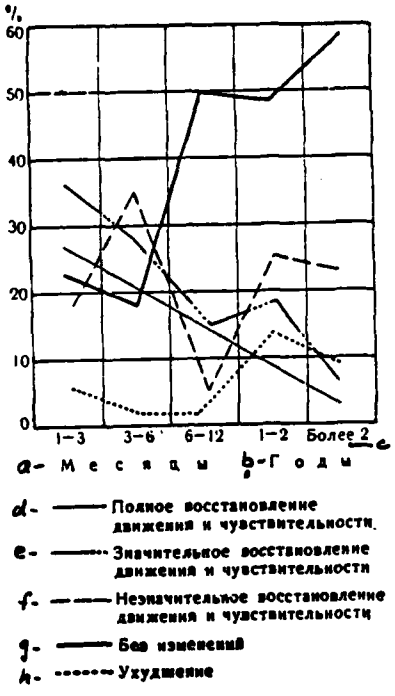


Fig. 163. The long-term results of surgical treatment with firearms wounds to the peripheral nerves depending on the time of operation.

a - Months; b - Years; c - Over 2; d - Complete restoration of movement and sensation; e - Significant restoration of movement and sensation; f - Insignificant restoration of movement and sensation; g - No change; h - Deterioration.

/444

Fig. 164. The long-term results of surgical treatment with firearms wounds to the peripheral nerves depending on the time of observation.

a - Years; b - Complete restoration of movement and sensation; c - Signigicant restoration of movement and sensation; d - Insignificant restoration of movement and sensation; e - No change; f - Deterioration.

The time necessary for judging the results of the treatment /445
fluctuates from 3 to 7 years after the operation, which is well illustrated by fig. 164. Here we should note an ascending curve of complete restoration of movement and sensation over a period of 4 years. At the same time, there is almost simultaneous growth in the curve showing the absense of restoration. These data allow us to draw a very important conclusion on the course of restoration of the lost function. In those cases where the restoration of function begins and slowly progresses, we may anticipate good results and should persistently conduct post-operative conservative treatment. However, in cases where over a prolonged period of time there is no hint of restoration, repeated operations are indicated. Experience has shown that the possibility of functional restoration of a damaged nerve trunk is so great and is retained for such a long time after the injury is sustained that conclusions on the presence of irreversible phenomena should be drawn only in those cases where stable loss is particularly acutely expressed, and only then should indications for orthopedic operations on the osteo-muscular apparatus of the extremity be presented.

A rather significant role in the evaluation of outcomes of surgical treatment of peripheral nerve injuries is played by the comparison of the data from immediate results and long-term results after the operation (fig. 165). These data, which reflect the relationship between the immediate and the long-term results, show that complete restoration of a lost function with an observation time of over half a year was noted in 0.2% of the cases, and with observation after 7 years -- in 18.7% of the cases. Also corresponding to these figures are the figures which illustrate the absence of change with these same observation times. Thus, in 6 months after the operation there was no change in 73.0% of the cases, while

7 years later there was no change in only 23.3% of the cases. These data clearly illustrate the dynamics of restoration of a lost function after an operation for a nerve trunk injury and illustrate that the longer the observation time after the operation, the better the results of the functional restoration.

Of exceedingly great significance and much interest are the data from materials of in-depth study which show the times for the appearance of restoration in movement and sensation after surgical treatment.

From these it is evident that improvement in the motor functions was observed first and was most expressed after an operation for injury to the leg nerves, then the radial nerve, and finally after operations for injuries to the sciatic nerve. The restoration of movement is noted on the average starting with the sixth month after the operation. /446
Sensitivity disruptions were restored first of all after the operation for injury to the radial nerve and last -- with injury to the ulnar nerve.

Figures 166 and 167 present the data for the restoration of movement and sensation characteristic in isolated as well as in combined injuries to the upper and lower extremities. The regularities noted in the free data are also manifested in the data on the individual nerves. The brachial plexus stands out as an exception, where there are many specifics on which attention should be focused, since the proper evaluation and operative treatment of these injuries is the most difficult.

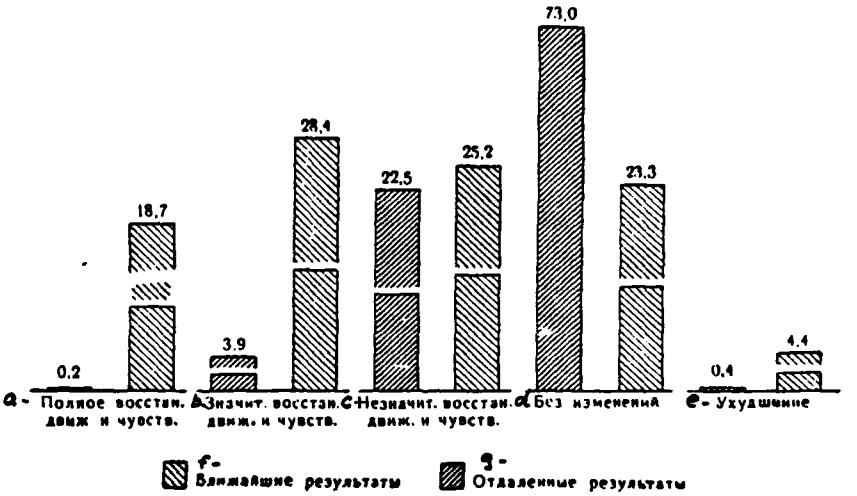


Fig. 165. The immediate and long-term results of surgical treatment in firearms wounds to the peripheral nerves.

a - Complete restoration of movement and sensation; b - Significant restoration of movement and sensation; c - Insignificant restoration of movement and sensation; d - No change; e - Deterioration; f - Immediate results; g - Long-term results.

In evaluating the long-term results of operations on the brachial plexus, it is always necessary to strictly delineate the restoration obtained as a result of compensation from the restoration which sets in after true regeneration. In confirmation of this it is necessary to present the following data. Of 86 wounded patients operated for firearms wounds to the brachial plexus (Institute for Neurosurgery imeni Akademic N. N. Burdenko), 68 patients were studied for a period of over 6 months. Twenty-nine of these were repeatedly studied at the institute, and subsequently 53 patients were studied for over a year. Of these, 26 were subjected to repeated examinations. This period of observation gives significant materials on the restoration of function in most cases. Over a period of 18 or more months (the time in which

the presence of regeneration is generally manifested), 46 operated patients were observed. Of these, 21 were subjected to secondary examinations. Within the course of 2 years or more (i.e., the time which is generally sufficient for completion of regeneration after surgery on the brachial plexus), 38 operated patients were studied. Of these, 16 were subjected to repeated examinations.

An analysis of the data obtained after thorough study in repeated examinations of contingents of wounded patients allows us to draw a number of conclusions. Here we must note

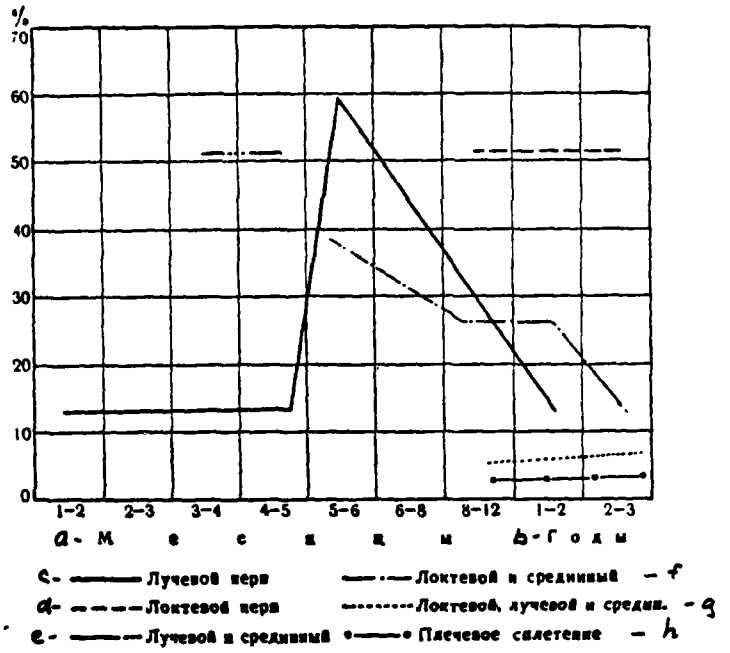


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Fig. 166. The time of restoration of sensation after surgical treatment with injuries to the nerve trunks of the upper extremities.

a - Months; b - Years; c - Radial nerve; d - Ulnar nerve; e - Radial and median; f - Ulnar and median; g - Ulnar, radial and median; h - Brachial plexus.

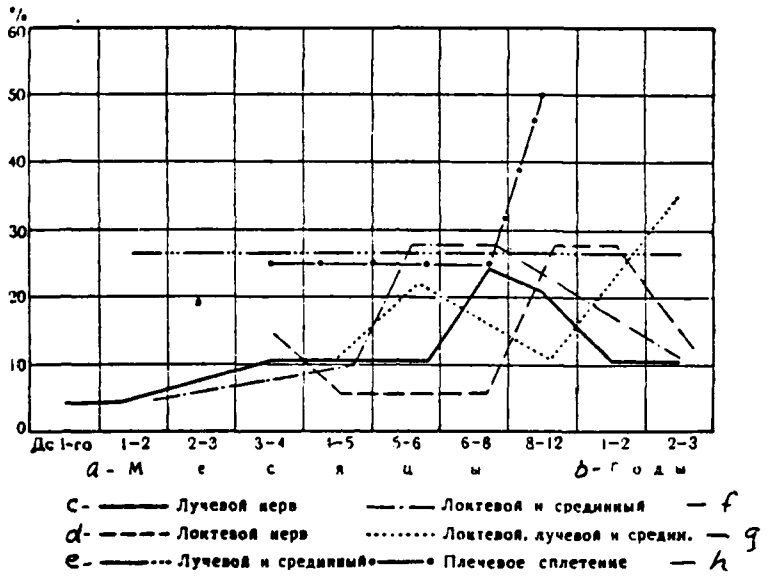


Fig. 166a. The times for the restoration of movement after surgical treatment in firearms wounds to the peripheral nerves of the upper extremities.

a - Months; b - Years; c - Radial nerve; d - Ulnar nerve; e - Radial and median; f - Ulnar and median; g - Ulnar, radial and median; h - Brachial plexus.

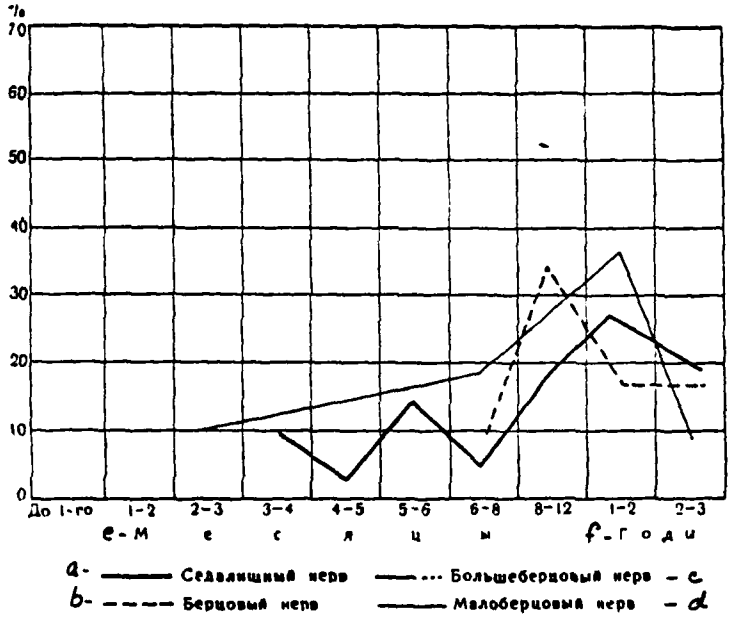


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Fig. 167. The times for the restoration of movement after surgical treatment of wounds to the peripheral nerves of the lower extremity.

a - Sciatic nerve; b - Leg nerve; c - Tibial nerve; d - Fibular nerve; e - Months; f - Years.

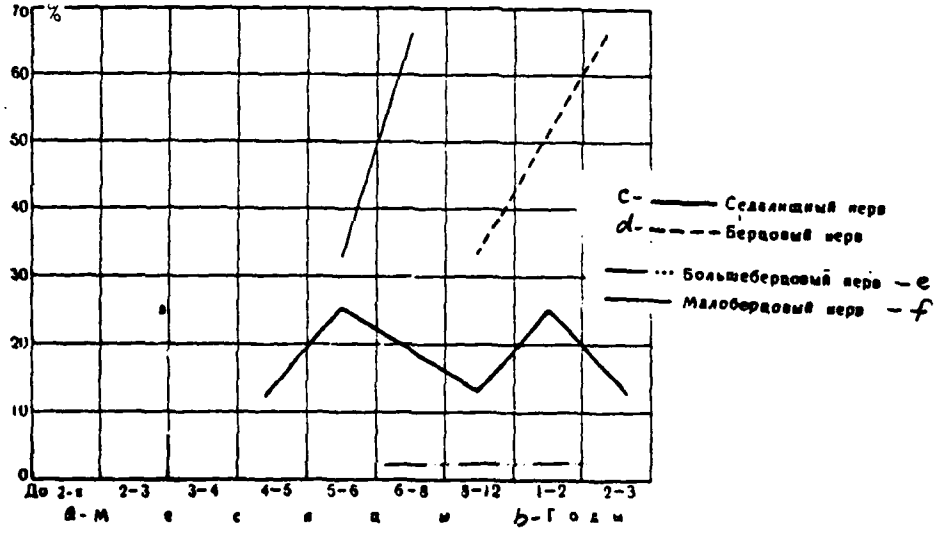


Fig. 167a. The times for the restoration of sensation after surgical treatment of injuries to the peripheral nerves of the lower extremity.

a - Months; b - Years; c - Sciatic nerve; d - Leg nerve; e - Tibial nerve; f - Fibular nerve.

that the data presented by most authors on the long-term /449
results of operations on the brachial plexus (A. V. Bondarchuk, N. B. Chibukmakher and others) yield in a quantitative sense and are studied in less detail.

The data of the Institute for Neurosurgery imeni Akademik N. N. Burdenko allow us to conclude that suture operations on the trunks of the brachial plexus performed within the first 8 months after the injury is sustained give approximately the same results. We were unable to note a difference in the results of nerve suture application within the first 3 months and in 3-8 months after the injury.

Among the 58 wounded patients who were studied for over 6 months after the operation resulting from firearms injuries to the brachial plexus, 20 of them underwent nerve suture application. In 4 cases, restoration was observed after the suture application. In 7 cases, incomplete restoration of function was noted. In 6 cases the improvement was not necessarily associated with the suture application to one trunk or another, and could have been conditioned by compensation. In 3 cases there was no improvement. Comparing the results depending on the times, we may conclude that the best results are obtained in those patients who underwent nerve suture within the first 8 months after sustaining their injury. Full restoration of function was observed only after suture application to the proximal sections of the plexus (upper primary trunk and lateral secondary trunk). Suture application to the seventh cervical root of the inferior primary trunk, the posterior and medial secondary trunk, as a rule, facilitated the restoration of function of most muscles in the arm and forearm. However, the muscles of the hand were either not restored or were restored to a very

slight degree. The latter relates in equal degree also to the proper extensors of the thumb. It should be indicated that restoration, which was practically satisfactory but not always complete, was observed in individual cases when the defects of the medial and posterior secondary trunks of the plexus were replaced by means of transfer of the radial nerve to the brachium and of the ulnar nerve to the ulnar region in the anterior bed of the brachium. Individual cases of unquestionable improvement resulting from regeneration were observed also after suture application or implantation performed in the second year after the injury was sustained. All the cases of suture application to the trunks of the plexus after 2 years since the time of injury had elapsed did not give any symptoms of regeneration.

Of 10 prolonged observations of cases of partial suture of the brachial plexus nerve trunks, full restoration of the volume of movement was noted in 5 cases. In none of these cases were the systems innervating the small muscles of the hand excluded. In 5 cases, partial improvement was observed. In 3 of these, where the systems innervating the hand muscles had been damaged, these remained paralyzed (fully or partially). An evaluation of the results of primary suture of the brachial plexus trunks is difficult, since the restoration observed in these cases may be conditioned by compensation caused by intact fibers of excluded (due to reticular structure) trunks of the plexus. Of 19 cases observed after neurolysis, full restoration of the volume of movement was observed in 13 of them. In 5 cases there was partial improvement, and in one case there was no change.

The restoration and improvement observed after neurolysis operations on the trunks of the brachial plexus cannot be convincingly associated with surgical interventions. They

may develop as a result of compensation and replacement (as also in the cases of partial suture), as well as a result of spontaneous regeneration.

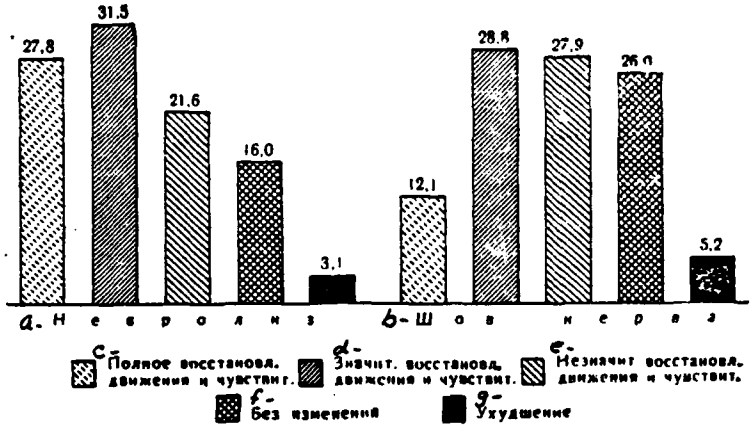


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Fig. 168. The long-term results after surgical treatment in peripheral nerve injuries depending on the character of the operation.

a - Neurolysis; b - Nerve suture; c - Complete restoration of movement and sensation; d - Significant restoration of movement and sensation; e - Insignificant restoration of movement and sensation; f - No change; g - Deterioration.

A more detailed presentation of the results of surgical treatment of the brachial plexus is presented because this section is difficult and has been less developed.

Two basic operations -- neurolysis and nerve suture -- have become widespread. Fig. 168 illustrates the long-term results depending on the character of surgical treatment. These operations -- neurolysis and nerve suture -- cannot be compared or generalized. They should be studied separately, since the indications, anatomical essence and pathologo-anatomical changes have completely different

expression in each of them, in connection with which an unfavorable effect with neurolysis may be related to those cases of injury where nerve suture was indicated. Based on the data in fig. 168, we must assume that in the cases where in 21.6% there were insignificant improvements, in 16.0% there was no result and in 3.1% there was deterioration, better results could have been obtained with suture application.

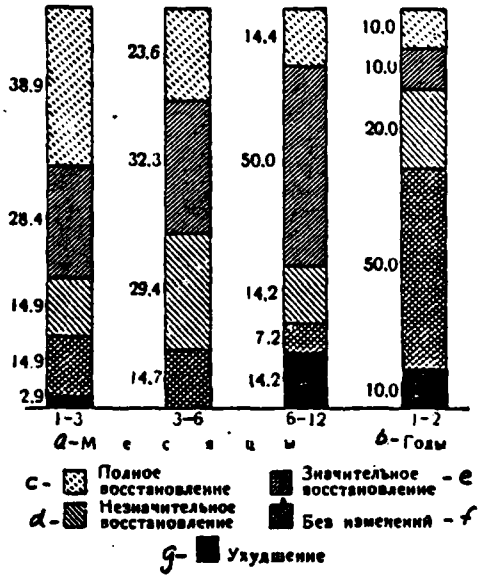


Fig. 169. The long-term results after surgical treatment in firearms wounds to the peripheral nerves depending on the time of operation with neurolysis.

a - Months; b - Years; c - Complete restoration; d - Insignificant restoration; e - Significant restoration; f - No change; g - Deterioration.

The restoration of nerve conductivity after suture application was noted in 68.8% of the cases. With continued treatment this percentage, of course, will increase. It is known that with properly performed treatment, nerve conductivity progressively improves within the course of a certain /451

time. With injury to the major nerves, as for example the sciatic, this may last up to 4 years from the moment of the operation.

More detailed data on the results of neurolysis and nerve suture application with consideration of the specifics of each nerve, its anatomical location and combination of injuries are presented in fig. 171, 172, 173, and 174, which summarize the long-term results according to the materials for the development of illness histories.

Aside from the presented data, we may also cite the data of certain authors regarding the long-term results of fire-arms injuries to the peripheral nerves (table 42).

Table 42

| Name of author | No. of wounded observed at various times | Full restoration of movement and sensation | Significant improvement in movement and sensation | Insignificant improvement in movement and sensation | No change | Deteriotation |
|---|---|---|---|---|---|---|
| | in percentages | | | | | |
| A.A. Dikova | 250 | 24.8 | 38.4 | 12.8 | 22.8 | 1.2 |
| P.A. Kovalenko | 53 | 14.4 | 46.6 | 17.1 | 21.9 | -- |
| P.A. Kartashev | 281 | 18.6 | 27.7 | 35.1 | 5.9 | 2.7 |
| A.Yu. Sozon-Yaroshevich | 137 | 19.5 | 45.1 | 23.9 | 10.6 | 0.9 |
| D.G. Shefer | 216 | 28.3 | 30.5 | 26.3 | 14.9 | -- |
| K.P. Chikovani | 300 | 20.6 | 33.4 | 24.4 | 21.6 | -- |

The data concerning the outcomes after surgical treatment after nerve trunk injuries, according to the materials of B. G. Yegorov and M. A. Nikitin, are based on 3,207 observations with evaluation of long-term results in 631 patients and are presented in fig. 169-170. They illustrate the long-term results of neurolysis and nerve suture application

at various times after the operation.

Of the materials presented in fig. 169 it is evident that neurolysis operations performed within the first 3 months after injury give the most favorable outcomes. Comparing the data which characterize later times of intervention, we may see that in the latter cases the effectiveness after neurolysis is reduced, evidently as a result of the increasing pressure on the nerve trunk by a scar and as a result of deep irreversible changes developing in the muscular and osteo-articulatory apparata.

From fig. 170 it is evident that nerve suture application performed at a period before 6 months from the time of injury leads to the most favorable outcomes. In later periods the effectiveness of this operation is reduced due to increased diastase in the nerve endings, deep necrotic changes in the tissue of the peripheral and central nerve segment, and changes in the muscular and osteo-articulatory apparatus.

The data of B. G. Yegorov and M. A. Nikitin which are presented above have the specific feature of not reflecting one methodology used by the two surgeons and uniform preparation before the operation or post-operative treatment.

It is evident from fig. 169-170 that the nerve suture and neurolysis performed before 3 months has elapsed from the time of injury give incomparably better results than later operative interventions.

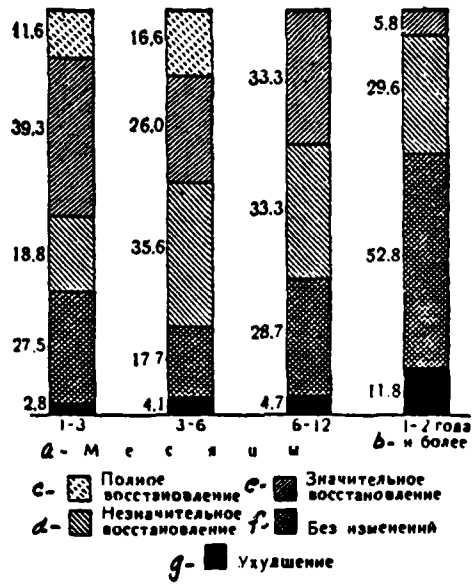


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Fig. 170. The long-term results after surgical treatment with firearms wounds to the peripheral nerves depending on the times of the operation with nerve suture.

a - Months; b - 1-2 years or more; c - Complete restoration; d - Insignificant restoration; e - Significant restoration; f - No change; g - Deterioration.

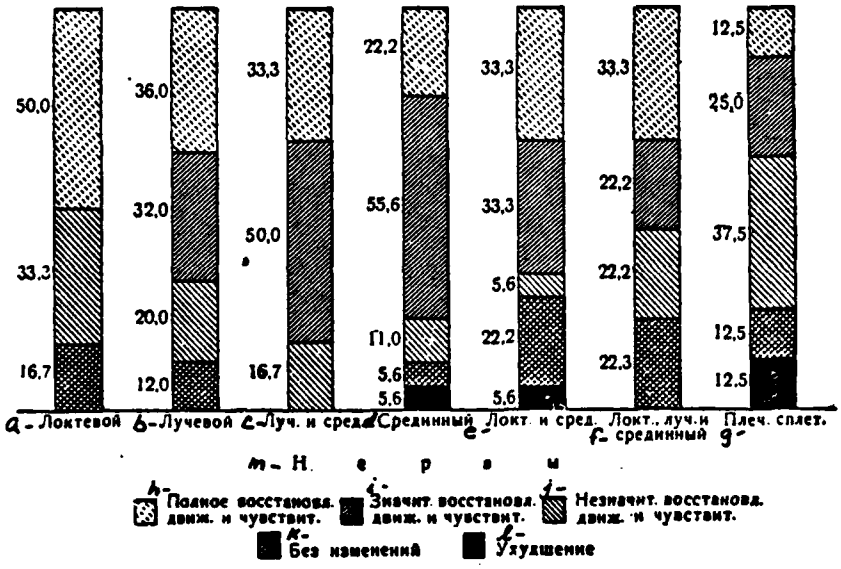


Fig. 171. The long-term results after surgical treatment in firearms wounds to the peripheral nerves of the upper extremity in connection with the character of the operation (neurolysis).

a - Ulnar; b - Radial; c - Radial and median; d - Median; e - Ulnar and median; f - Ulnar, radial and median; g - Brachial plexus; h - Complete restoration of movement and sensation; i - Significant restoration of movement and sensation; j - Insignificant restoration of movement and sensation; k - No change; l - Deterioration; m - Nerves.

Of significant importance in the evaluation of long-term results of surgical treatment is the dynamics of the restoration of lost function after the neurolysis operation on individual nerves of the upper extremity (fig. 171) and the lower extremity (fig. 172).

From the data presented it is evident that the best results of functional restoration were noted after neurolysis in cases of injury to the radial nerve (88.0%), followed by the ulnar nerve (83.3%). The worst outcomes were observed after neurolysis for cases of combined injuries to the median and ulnar nerve (72.2%). The most favorable long-term results were observed after neurolysis of the leg nerves. The worst outcomes of these operations were noted with injury to the sciatic nerve (78.1%).

The most favorable long-term results after suture application were observed with injury to the median nerve (81.2%), followed by the ulnar (75.0%), while the least effective was nerve suture application in cases of injuries to the radial nerve. The best results in terms of functional restoration with suture application due to injury of the peripheral nerves of the lower extremities were noted after surgery on the fibular nerve (90.0%). Under these same condition, the restoration in the function of the sciatic nerve was noted in only 47.8% of the cases (fig. 173 and 174).

Summarizing the data obtained by means of studying the long-term results with an evaluation of the restoration of movement and sensation, it is also necessary to cite the interesting materials relating to the restoration of work capacity. It is evident from fig. 175 that wounded patients who received injuries of the peripheral nerve trunks could

return to ranks or to peacetime labor thanks to the proper organization of their treatment. Here we should note that according to the data of long-term results, over one-fourth of all the wounded (28.0%) could perform heavy physical labor after undergoing operations for nerve trunk injury.

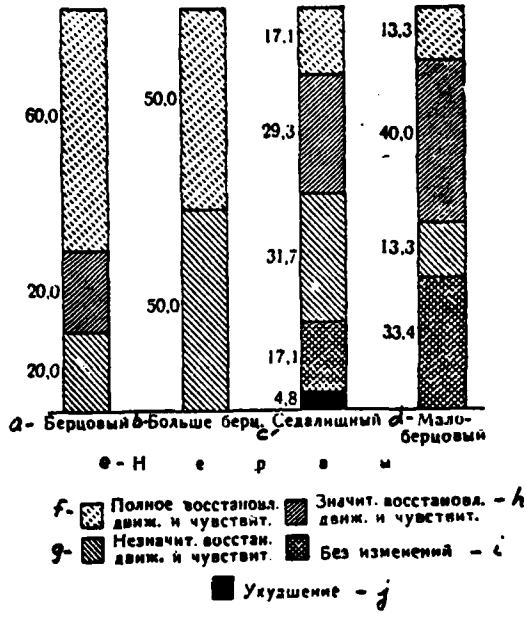


Fig. 172. The long-term results of surgical treatment for injuries to the nerve trunks of the lower extremities in connection with the character of the operation (neurolysis).

a - Leg; b - Fibular; c - Sciatic; d - Tibial; e - Nerves; f - Complete restoration of movement and sensation; g - Insignificant restoration of movement and sensation; h - Significant restoration of movement and sensation; i - No change; j - Deterioration.

Exceptional interest is presented by the data of long-term results of treatment of complications accompanying nerve trunk injuries. It was established that wounded patients with mild forms of causalgia were cured as a result of the

application of physical methods, x-ray therapy, novocaine blocks, and other methods. Wounded patients with severe forms were operatively treated. The arterial desympathization operation should be regarded with some hesitation, since the study of a relatively large volume of material speaks of the low percentage of recovery.

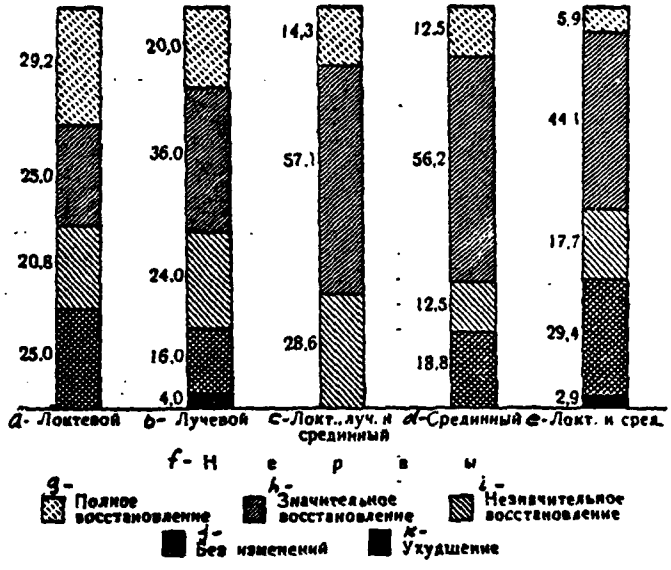


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Fig. 173. The long-term results after nerve suture application with injuries to the peripheral nerves of the upper extremities.

a - Ulnar; b - Radial; c - Ulnar, radial and median; d - Median; e - Ulnar and median; f - Nerves; g - Complete restoration; h - Significant restoration; i - Insignificant restoration; j - No change; k - Deterioration.

The operation of nerve severance should be regarded negatively. /455

The methodology of operative intervention which ensures the best results is comprised of two moments: 1) the elimination of the focus of irritation -- neurolysis and freeing

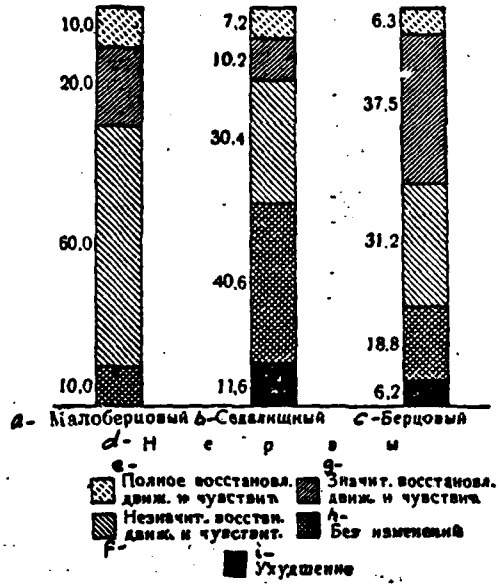


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Fig. 174. The long-term results after nerve suture application with injury to the peripheral nerves of the lower extremities.

a - Fibular; b - Sciatic; c - Leg nerves; d - Nerves; e - Complete restoration of movement and sensation; f - Insignificant restoration of movement and sensation; g - Significant restoration of movement and sensation; h - No change; i - Deterioration.

the accompanying arteries from scars; 2) postganglionic and /455
preganglionic sympathectomy. For the upper extremity, the best method was the removal of the third-fourth thoracic ganglion; for the lower extremity -- the second lumbar.

There are four factors (mechanical, pain, dystrophic and psychogenic) which in various combinations may be the reasons for contractures. It is necessary to clarify in each individual case which of the factors is the dominant or leading one, and depending on this the contracture should be related to one group or another. The determination of the character of the contracture has not only a theoretical

interest, but also makes it possible to establish a prognosis as well as the methods and duration of treatment.

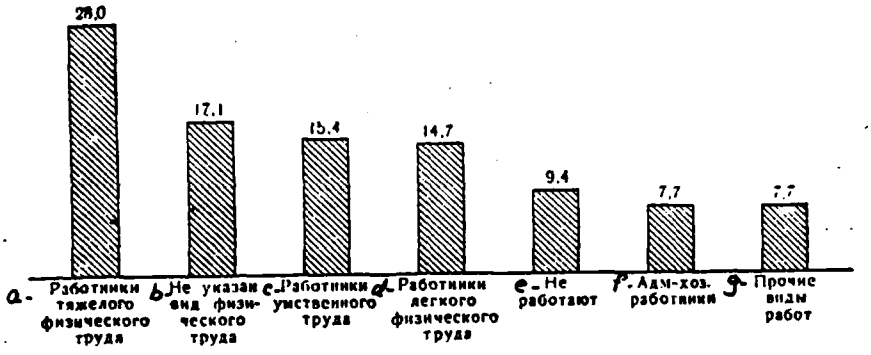


Fig. 175. The restoration of work capacity after surgical treatment of the peripheral nerves.

a - Workers engaged in heavy physical labor; b - Type of physical labor is not indicated; c - Workers engaged in intellectual labor; d - Workers engaged in light physical labor; e - Not working; f - Administration-management workers; g - Other types of work.

On the basis of a study of the materials for the development of illness histories we must conclude that the most easily and rapidly treatable were the neurogenic contractures in which mechanical moments prevailed. Used successfully in these types of contractures were by-stage plaster bandages, clamps with elastic bands, and in individual cases -- tenotomy. With slight contractures, exercise treatment and physiotherapy were successfully used.

In contractures where the pain component is prevalent, it is first necessary to eliminate the pain factor by means of neurolysis or removal of the vegetative ganglia, after which orthopedic treatment and physiotherapy should be used.

The effectiveness of the treatment in such a sequence with painful contractures was fully satisfactory.

The case was entirely different in treating dystrophic contractures in which significant pathologo-anatomical changes occurred in the soft tissues, bones and joints. As illustrated by the experimental studies and the study of materials from the Great Patriotic War, in injury to the vegetative elements of the nervous system there are a number of stable changes not only in the skin (swelling, cyanosis, hyperhydrosis, hypertrichosis), but also in the tendons, ligaments, synovial capsule and articular cartilage. The tendon fibers are replaced by a rough fibrous connective tissue and are corrugated. The same occurs with the ligaments. The synovial membrane loses its villose properties, the amount of synovial fluid decreases, the the cartilage /456 surfaces of the joints lose their sheen. The so-called trophoneurotic osteoporosis occurs in the bones. It is quite understandable that in the presence of such pathologo-anatomical changes it is impossible to eliminate the dystrophic contracture by orthopedic measures along. It is necessary to act -- surgically and by physiotherapy -- on the vegetative elements of the nervous system. The treatment of such dystrophic contractures lasted for many months (B. N. Tsypkin).

In the treatment of psychogenic contractures, psychotherapeutic measures in combination with electrotherapy were primarily used. The correction of psychogenic contractures under narcosis did not give stable effects.

The experience of the Great Patriotic War allowed us to conclude that for treatment of neurogenic contractures it

is necessary to have the combined efforts of the orthopedist and neurosurgeon. Under wartime conditions, only the cooperative work of the orthopedist and the neurosurgeon provided effective treatment for peripheral nerve injuries.

According to the materials of the Great Patriotic War, in reflex contractures the best results were obtained from by-stage surgical treatment, elimination of the focus of irritation by means of freeing the central apparatus from stimulation or overstimulation by means of: 1) neurotomy -- its results are not uniform; this operation must be used in rare cases as an extreme measure; 2) novocaine block according to Vishnevskiy gives better results and may be recommended for widespread application; 3) if the novocaine block of sympathetic ganglia leads to unstable positive results, preganglionic sympathectomy should be recommended (according to A. M. Grinshteyn).

Alcoholization of the ganglia should be excluded as chemical trauma (A. D. Speranskiy).

From the materials of the Institute of Neurosurgery imeni Akademik N. N. Burdenko it is evident that the formation of trophic ulcers after firearms injuries to the peripheral nerves is a result of the action of a number of endogenic and exogenic factors on the injured extremity. In studying the dependence of the formation of trophic ulcers on the degree and character of the nerve injury it was established that these ulcers develop only in zones with disrupted sensitivity. An analysis of the presented material showed that in zones with retained sensitivity, not a single case of ulceration was noted. Particularly important is the fact that if in the process of the nerve regeneration after suture application there is a healing of the ulcer with its

subsequent recurrence, the new ulcer arises not on the previous place, but in a new area, always where sensitivity has been disrupted.

A no less necessary condition preceding the formation of an ulceration is local (in relation to the area of the ulceration) injury.

An exceptionally stable trait characterizing trophic ulcers is infection. The presented data convincingly demonstrate that infection cannot be viewed only as a factor accompanying and complicating trophic ulcers. Infection, being initially one of the factors which facilitate the development of the ulcer, subsequently becomes one of the basic moments determining the persistence of this illness and the frequency of its recurrence.

An analysis of the cases of nerve trunk injuries with trophic ulcers from the viewpoint of clarifying the reasons causing and sustaining these ulcers as observed at the Institute of Neurosurgery imeni Akademik N. N. Burdenko showed that they are a consequence of random complications. /457 Each of these complications takes place quite frequently with any injury, but under certain conditions it is not significant and does not lead to the formation of an ulcer.

The basic factors are: 1) a focus of irritation at the point of the nerve injury; 2) the disruption of peripheral blood circulation; 3) sensitivity disruption; 4) faulty position of the extremity and abnormal static conditions; 5) local trauma; 6) infection.

Each of the listed factors individually or in certain

combination may occur in the course of the injury and may lead to the formation of an ulcer.

A critical evaluation of the results of treatment of trophic ulcers on the extremities allows us to draw but one conclusion: the reason for the low effectiveness of surgical interventions consists in the erroneous opinion on the possibility of affecting the sum of factors determining the given illness as a whole by intervening on some single link. The principles of surgical intervention must be based on a complex of sequential influences on the individual components of the given illness.

In concluding our evaluation of the long-term results of surgical treatment of firearms injuries to the peripheral nerves, we must note with all due emphasis that the method of surgical treatment in firearms injuries to the peripheral nerve trunks is very simple and is accessible not only to neurosurgical specialists, but also to any surgeon. The indications for operative treatment should be broadened while adhering to the established times with consideration of clinical and theoretical data.

The analysis of the long-term results of surgical treatment of firearms wounds to the peripheral nerves given above gives us reason to affirm that Soviet neurosurgeons and surgeons brilliantly handled the rather difficult problems facing them during the war.

The work of each medical worker, each individual doctor, each published work did not go unnoticed and became the basis for the vast experience of Soviet medicine during the Great Patriotic War. As a result of the accumulated experience, the study of peripheral nerve injuries was elevated to a higher level and enriched our Soviet medicine with

new achievements. Therefore, the portentous and inspiring words of our great teacher and leader, comrade I. V. Stalin, also applied to us, the medical workers and participants in the Great Patriotic War: "Our intelligentsia has enriched Soviet science and technology, culture and art with new outstanding achievements and discoveries ... The Patriotic War has shown that the Soviet people are capable to performing miracles and of coming out victorious from the most difficult trials" (Proclamation of May 1, 1944).

## CONCLUSION

### General conclusions on rendering specialized aid in firearms injuries to the peripheral nerves

The battles of the Great Patriotic War engendered and /458
strengthened Soviet military field neurosurgery, the basis of which is the singularity in understanding the development of the pathological process of firearms wounds, the substantiation of principles of surgical work under field conditions, the successiveness in servicing the wounded at various stages of evacuation, and the clear and sequential documentation which makes it possible to perform accurate sorting of the wounded.

The Great Patriotic War forced us to conduct a deep analysis of the theoretical and clinical data on firearms injuries to the peripheral nerves and to subject certain antiquated positions to radical changes.

During the war, the existing pathomorphological data on combat injuries to the peripheral nerves were reviewed, the concepts of the character of their degenerative and regenerative changes were significantly expanded, the dynamics of the course of the wound process were comprehensively studied, as a result of which an exhaustively complete pathomorphological description of the forms of residual conditions due to firearms injuries to the peripheral nerves was presented.

The experience of the Great Patriotic War allowed us to develop a rational classification of the peripheral nerve

injuries which may be used as a basis for diagnosis, clinical practice and treatment.

The medical service of the Soviet Army was always built on scientific principles. All the achievements of modern Soviet science were used for the timely and complete treatment of the troops and were widely introduced into the practice of the army medical service.

A great achievement of the Soviet Army Medical Service was the organization of specialized aid, including neurosurgical aid, and its proximity to the combat zone.

With firearms injuries to the peripheral nerves at the most immediate stages of evacuation, the attention of the physicians was fixed primarily on rendering immediate aid and on the proper treatment of the wound. In the preliminary treatment of the wound, clarification of the nerve injury was rarely performed. If exposed nerve ends were found, economic section of the ends was allowed [instruction of the USSR Narkomzdrav (B. G. Yegorov)]. To avoid tension of the nerves, it was also recommended to bring their ends together with a tension suture, which remained until the secondary operation. Individual authors recommended the use of early /459 suture. Where conditions permitted, as occurred during the Leningrad seige, the application of the primary suture to the injured nerve was done in some cases within the first 6-36 hours (A. G. Molotkov). However, early suture was not recommended as being mandatory. A study of the results after the application of an early suture showed it to have little effectiveness.

The organization of by-stage treatment during the war

made it possible to work out the shortest route to specialized home front institutions for wounded patients with nerve injuries.

The level of diagnostics for nerve trunk injuries was considerably increased during the Great Patriotic War, especially as compared with the materials of previous wars. Of great significance were the auxiliary diagnostic studies and the special study of disrupted functions in cases of nerve trunk injuries. The introduction of electrophysiological methods of study allowed Soviet physiologists to establish many new positions (P. K. Anokhin, Yu. M. Uflyand, K. M. Shapiro and others) which improved the diagnostics of the nerve injury.

The detailed study of the character of nerve trunk injuries and the specifics of their course made it possible to isolate a large number of different clinical syndromes in peripheral nerve injuries (M. M. Ammosov, S. N. Davidenkov, L. Ya. Pines, N. N. Pyatnitskiy, I. Ya. Razdol'skiy, D. G. Shefer and others). Soviet neuropathologists and neurosurgeons in a number of works presented comprehensive descriptions of the complex syndromes of causalgia, reflex contractures, paralyses, trophic ulcers, and recommended methods for their treatment.

One of the decisive factors ensuring the success of specialized treatment for firearms injuries to the peripheral nerves was the correct strict organization of medical aid at the stages of evacuation. A number of corresponding measures were performed: 1) specialized neurosurgical hospitals were created, as well as neurosurgical sections in general surgical hospitals at the front as well as on the home front; 2) army and front line hospital bases were

provided with neurosurgical hospitals and departments, which were organized on the baseis of special institutes and clinics; all the hospitals and departments were staffed with neurosurgeons and neuropathologists; 3) at front medical headquarters and medical sections, at military district headquarters, at evacuation hospital headquarters of health maintenance sections the following specialists were designated -- chief neurosurgeons and chief neuropathologists responsible for the correct organization and for the proper treatment of wounded patients with peripheral nerve injuries.

Principles of by-stage treatment of peripheral nerve injuries were established. Particular attention was given to the diagnosis of peripheral nerve injuries: the preliminary diagnosis was given at the medical battalions and in the front line hospitals, and the final diagnosis was pronounced in the second line army hospitals with the mandatory participation of specialist neuropathologists and neurosurgeons.

During the war, the question of the times for operative intervention in cases of firearms injuries to the peripheral nerves, the indications and counterindications for this intervention, was very acutely presented.

The question of the times for operative intervention with peripheral nerve injuries was discussed throughout the entire course of the Great Patriotic War. It was generally accepted that the most favorable period for performing surgery is within the first 6 months after the injury is sustained. It is impossible to answer the question on time of surgery without individualizing the cases of peripheral nerve injury. With uncomplicated wound healing, the optimal

conditions for nerve regeneration are created in the second and third month after the injury is sustained. With a complicated course the time fluctuates significantly.

The experience of the war introduced a certain clarity into the question of times of operative intervention on nerves. The most expedient time for the operation was considered to be the period of approximately 3 months from the moment of injury and 2-3 weeks after healing of the wound.

With pain syndromes, particularly with causalgia or presence of foreign bodies, the times for surgery were shortened even to 2 months, regardless of wound healing. With complete anatomical severance and with the absence of particular counterindications (infection of the wound and the bone), the times for operative intervention were also reduced to 2 months from the moment of injury.

The efforts to reduce the time for treatment of wounded patients with nerve trunk injuries motivated clinical practitioners to seek out possibilities for earlier operative intervention on the nerve trunks, up to attempts at restoring their continuity even in purulent wounds using new antiseptics, primarily sulfamides and penicillin.

However, it should be noted that this methodology did not receive the widespread approbation of surgeons. Nevertheless, as a result of the review of previously existing notions, the times for the operative restoration of nerves were brought closer to the moment of wound healing. Operations on the peripheral nerve trunks began to be successfully performed in the nearest 3-4 weeks after wound healing, and sometimes even a little sooner.

A large role in the correct and timely provision of medical aid was played by the ORMU neurosurgical groups and the created specialized hospitals and specialized sections, beginning with the military region at all the subsequent stages of evacuation.

As a result of these measures, treatment took on the character of a structured system, in which the elements of purely operative technique were closely interwoven with a series of preliminary and subsequent treatment measures (rational immobilization, electro-hydrotherapy, exercise therapy, work therapy).

For the extent of the Great Patriotic War, improvements of an organizational character went parallel with the accumulation of experience, the improvement of operative technique, as well as the development and improvement in the methodology of pre-operative and post-operative treatment.

It should be noted that, along with the huge practical work conducted by neurosurgeons, neuropathologists and surgeons, at all the stages of evacuation there was in-depth theoretical work directed toward the study of the optimal conditions of regeneration, the best and most timely methods of surgery, particularly rational approaches to the nerve trunks which would protect them against subsequent cicatrical compression. At the same time methods were being worked out for accelerating the restoration of physiological conductivity. Methods were being sought for combatting complications /461
in nerve trunk injuries -- causalgia and phantom pains, etc., utilizing the data on the connections of the so-called "animal" and "vegetative" nervous system.

In regard to operative methods, the necessity was stressed for extremely careful treatment of the nerve tissue, thorough preparation of the tissues surrounding the nerve, the significance of testing with electrical current at various levels of the central end of the injured nerve was noted, as well as the importance of thoroughly stopping hemorrhaging from vessels in the surrounding tissues and the nerve trunk itself. Exposing the nerve too much was not recommended, as well as pulling it out of the surrounding tissues in order to bring the ends together. Attention was directed toward the necessity of creating a bed comprised of healthy tissues for the nerve to be submerge into.

The most physiological method should be considered the nerve suture.

In all the specialized hospitals, the principle of complex treatment of injuries to the peripheral nervous system was promoted. The hospitals were equipped with physiotherapeutic apparata. Electro-light-hydrotherapy were widely used. Mud therapy, exercise therapy, kineso-therapy, mechanotherapy and work therapy were successfully used, especially for purposes of preventing the formation of contractures and various deformations of the hands and feet in the presence of paresis and paralysis.

To avoid drooping of the hand (with injury to the radial nerve) and the foot (with injury to the fibular nerve), orthopedic apparata and footwear was prescribed.

As a result of the organization of specialized neuro-surgical hospitals and sections, the provision of these hospitals with the appropriate cadres and equipment, there

were significant shifts in the treatment in peripheral nerve injuries.

Thus, the strong organization of special neurosurgical aid in the USSR during the Great Patriotic War ensured to a significant degree the expansion of problems on the treatment of peripheral nerve injuries.

With complicated injuries, as: with simultaneous injuries of the vessels and bone fractures, acutely expressed pain threatening a condition of shock, in the process of preliminary surgical treatment the necessary operative interventions were performed: vascular ligation, reposition, removal of bone fragments and metal fragments with the mandatory subsequent immobilization, and direction to specialized hospitals as indicated.

Particular attention was given to see that after treatment of the soft tissues and bones, the retaining bandage provided the correct functional position of the extremity, and the formation of a limp hand or foot (with the presence of nerve damage) was not allowed.

Indications and counterindications for operative intervention were established.

Surgical intervention was considered indicated in the following cases:

a) with the syndrome of complete anatomical severance of the nerve;

b) with the syndrome of partial nerve severance as soon as the absence of improvement under the influence of previously

applied physical treatment methods became clear;

c) with pain syndromes, particularly those which usually arose after injury to the brachial plexus, the median and sciatic nerve, and those not subject to physical methods of treatment;

d) with the presence of a foreign body and bone frag- /462
ments next to the nerve which cause a pain syndrome;

e) with paralysis and contractures due to nerve trunk injuries.

Counterindications to operative intervention were primarily centers of purulent infection and an unfused bone fracture in the presence of osteomyelitis.

The question on the advisability of operative treatment in the presence of infection in the wound has remained unanswered. True, the measures of combatting infection have become broader and more effective: the early and complete treatment of the wound, the widespread use of antibiotics, the application of a delayed or secondary suture to the tissue have significantly reduced the severity of purulent complications and have shortened the time for wound healing. Bacteriological control and methods of provocation (N. N. Burdenko) have given reliable criteria for solving the problem of the possibility of operative intervention. In cases of wounds which would not heal for a long time, excision and secondary suture, plastic closure of the skin defects with simultaneous surgical intervention on the nerve and, finally, operation on the nerve with a non-epithelized and even purulent wound were used (A. N. Bakulev, M. I. Borovskiy,

Yu. Ya. Kaluzhskiy, V. V. Lebedenko). The latter have not yet received general approbation.

Thus, after prolonged suppuration and complication with gas infection, the waiting period was extended to a longer time (3 months after wound healing -- N. D. Zybin). With osteomyelitis, in order to reduce the treatment time, efforts were made to use sequestrotomy simultaneously with neurolysis (A. S. Lur'ye, D. G. Shefer), as well as operations on the nerve before liquidating the purulent process in the bone (P. A. Kovalenko, P. S. Kondrashev).

With injury to the bones, which often accompanies nerve injuries (according to the materials for the development of illness histories -- in 45.2% of the cases), operative intervention was put off until consolidation.

If the diagnosis was unclear, exploratory surgery was performed for purposes of clarifying it. This made it possible to be sure of the presence of a severance and to perform immediate suture application to the nerve (B. G. Yegorov).

The question of the expediency and possibility of treating damaged nerves simultaneously with the preliminary wound treatment remains unsolved.

A question of great significance from the practical standpoint is the replacement of large defects in the nerve with various types of implants. This question has not yet been conclusively answered, and of course, must receive immediate attention in scientific research studies.

We must consider it an established fact that surgical and )

conservative treatment in firearms injuries to the peripheral trunks of the nervous system may provide a maximal percentage of good outcomes. According to the materials for the development of illness histories, the latter reached 78.0%.

The methods of surgical treatment and physiotherapy, as well as the restorative therapy are simple and accessible to any doctor with a surgical background, with the condition of adhering to the basic rules directed toward the most careful treatment of the nerve tissue and the mandatory creation of all conditions in the operative wound and the organism which would ensure and stimulate regeneration.

Before operative intervention, neuropathologists at specialized and home front hospitals of a general type conducted a thorough clinical examination of the wounded patients, registering all the data in the case history card. The neuropathologist and surgeon or neurosurgeon jointly /463 solve the problems of surgical tactics and time of using physiotherapy before the operation, and especially after the operation, and the recommendation of mandatory work therapy. Particular attention should be given to the documentation of condition before the operation, the description of operative data, details of technique and the subsequent course, with thorough notations on the dynamics of the illness.

The outcome is the only indicator on the basis of which the correctness of organization and the quality of treatment may be evaluated. It is necessary to decisively combat the opponents of early diagnostics who base their opinions on the fact that early operations have not found a large number of proponents.

Early diagnosis is necessary not only for solving the problem of operative intervention, but also for clarifying the conditions of the nerve's readiness for regeneration.

An early diagnosis makes it possible to select the proper methods of combatting secondary changes in the extremity and to substantiate timely and correct splinting and timely direction of the patient to the appropriate treatment institutions for basic treatment. An analysis of illness histories has shown that early recognition led to the best treatment results.

One of the basic questions of treating injured nerves is the organization of a proper course of treatment for the patient before the operation and after the operation -- until the restoration of work capacity.

The battle with secondary changes in the extremity and the retention of good blood supply to the injured extremity play a huge role in retaining those potential capabilities in the peripheral segment which are the basis for the restoration of movement.

In the post-operative period it is necessary to have organization of the conservative treatment with the proper application of physiotherapy, mechanotherapy, and exercise therapy, etc.

Indications for endoneurolysis in cases of endoneural scars, internal neuromas and causalgia were rarely presented. Endoneurolysis did not receive a unanimous favorable evaluation, and more radical surgeons recommended nerve resection with suture application under the same conditions.

In cases of partial nerve severance (18.6%) with the formation of a lateral neuroma, resection of the afflicted section with suture application was used in 4.0% of the cases. N. B. Chibukmakher, not having obtained successful results on extensive material, declined the use of the partial resection and insisted on total resection with subsequent suture application.

With complete anatomical severance of the nerve (35.4%), which is not difficult to recognize in the later periods after the injury, economic excision of the ends and end-to-end suture application to the nerve became widespread. Efforts to replace silk sutures with adhesive plasma which were proposed abroad, or with thin tantalum wire received no support in this country, as well as the proposal of foreign surgeons to return to the tubulization of the suture area using tantalum foil, cellophane, etc. However, individual Soviet surgeons obtained favorable results by using insulation with hemostol, Formalin treated fetal membrane or catgut casing, etc. (V. V. Kovanov, G. Ye. Ostroverkhov, I. I. Kal'chenko).

In order to facilitate bringing the nerve ends together, as a rule, fixation of the extremity in the appropriate position was used or, under certain condition, nerve transfer.

Nerve suture application was used quite often. Accord- /464
ing to the materials for the development of illness histories, this was done in 52.8% of the cases, and according to the data of individual authors -- even in 95.0% (Sapozhnikov). According to the observations of individual authors, in the immediate 2 years after the suture application operation, improvement was noted in 61.5% of the cases (P. A. Kovalenko).

According to the data of Krivopusk, functional restoration was observed in 50.8% of the cases and improvement in 23.0%. According to the analysis of the long-term results of surgical treatment of peripheral nerves with suture application, complete restoration was established in 12.1%, and significant improvement in 28.8%.

With great divergence of the nerve ends and the total impossibility of bringing them together, all the previously proposed methods were utilized. Authoritative surgeons have long warned against the inadmissibility of double suturing with forced tension of the nerve ends and of the danger of intraneural hemorrhaging associated with this (N. N. Burdenko). Nevertheless, this method was used in a number of cases, although the evaluation given to it was quite restrained (N. B. Makhov). Heteroplasty with the aid of Formalin and alcohol-glycerine preparations was recommended by instruction of the USSR Narkomzdrav and was widely used in the first years of the war. However, later it began to be used only in those rare cases when other methods were impossible. Regeneration with the use of transplants was noted only in singular cases (N. I. Makhov), and only its initial signs were found (B. L. Smirnov). The rather frequent rejection of transplants (12.0% -- N. B. Chibukmakher, D. G. Shefer) and the lack of positive results in their application motivated many surgeons to reject heterogeneous transplants and to replace them with autoplasty (B. G. Yegorov). The method of nerve transfer earned reliability (radial and ulnar) (B. G. Yegorov, A. S. Lur'ye). In exceptional cases surgeons used the method of replacement (N. N. Burdenko, Z. I. Geymanovich) using for this a nerve whose function was less significant and suturing it with the peripheral end of the damaged nerve.

Among the new methods we must relate the operation of replacement with partial paralysis of the brachial plexus utilizing its short motor branches which was developed at the Institute of Neurosurgery imeni Akademik N. N. Burdenko. Also used were lateral anastomoses, myotization and other previously known methods which were almost ineffective, as a result of which they were rarely used (6.5% -- P. M. Krolevets).

Various proposals were made for the purpose of improving the access to the nerve trunks and plexuses. Among the number of new methods is the approach to the sacral plexus through an enlarged sciatic cut, tested at the Institute of Neurosurgery imeni Akademik N. N. Burdenko (I. M. Grigorovskiy).

Operations on the sympathetic system began to be used quite widely and for various indicators. They were done concommitantly, as for example, arterial denudation during neurolysis (A. Yu. Sozon-Yaroshevich) or additionally, for example, as a method to aid in regeneration (N. I. Makhov) or for purposes of combatting manifestations conditioned by the injury to the vegetative nervous system (causalgia, reflex contractures) (A. N. Bakulev, A. V. Bondarchuk, A. M. Grinshteyn, B. G. Yegorov, F. M. Lampert, A. Yu. Sozon-Yaroshevich and others).

Out country's science has priority in the application of preganglionic sympathectomy in cases of causalgia. This operation with removal of the third thoracic sympathetic ganglion in injury to the upper extremity and the second-third lumbar sympathetic ganglion in injury to the lower /465 extremity was substantiated and developed by A. M. Grinshteyn as early as 1939 and was brilliantly proven during

the Great Patriotic War in cases of causalgia as well as in reflex contractures and paralysis. Novocaine block of the sympathetic ganglion was widely used for purposes of diagnosis, prognosis, and especially treatment.

Orthopedic operations on the tendons and muscles also became accepted. During the Great Patriotic War they were developed in detail (N. N. Priorov, V. D. Chaklin, M. B. Topchibashev) and were often used in combination with operations performed on the nerves (G. Ye. Ostroverkhov) as a measure facilitation the retention of function during the period of nerve regeneration.

Subject to review was the question of treating trophic ulcers, which were often complicated by injuries to the bone (K. G. Terian, M. G. Ignatov and others). Trophic disruptions in the bones and joints which set in at early and late times after nerve trunk injuries were studied in detail with the consideration of x-ray data (Ye. M. Gaol'tsman, I. G. Lagunova and S. I. Rotenbert, D. G. Rokhlin and others).

The complex study of trophic ulcers at the Institute of Neurosurgery imeni Akademik N. N. Burdenko showed that here, aside from the aseptic resorption of the bone tissue, a great significance also belongs to the bacterial factor. This made it necessary during surgical treatment not only to focus attention on the primary injury in the nerve trunk, but also to radically resection the infectious center in the bone (K. G. Terian).

Positive results were obtained with the use of physiotherapy in the pre-operative period as well as after the operation, as well as in patients subjected only to conservative treatment. Immobilization and splinting, exercise

therapy, various methods of electro- and light therapy, balneotherapy and work therapy, recuperation at health resorts -- all entered into the treatment plan in a certain sequence.

Unlike foreign authors, who limited themselves to the publication of primarily statistical data demonstrating the usefullness of recuperation methods, Soviet scientists, along with a development of the methods of treatment, presented an in-depth analysis of the processes of restoration and functional compensation with a discussion of the mechanism of re-structuring at the center and the periphery during recuperation and re-training of the patients (L. G. Chlenov, A. V. Zaporozhets and others).

The outcomes of operative and conservative treatment have been published by numerous authors. However, the periods of observation varied, the grouping of outcomes by categories and the number of the latter were taken arbitrarily, and each author gave his own interpretation to the concepts of "recovery" and "improvement". Nevertheless, the results published by neurosurgeons working in sections where wounded patients with peripheral nerve injuries were concentrated and collecting material encompassing hundreds of cases present significant interest (B. G. Yegorov and M. A. Nikitin, N. B. Chibukmakher and many others).

The organization of successive complex treatment of patients with peripheral nerve injuries, the widespread exchange of experience during the war years provided the most correct route for solution of the problem of treating nerve trunk injuries.

For the first time in wartime history, .. clearly organized specialized neurosurgical aid for firearms wounds to the peripheral nerves was placed at the service of the military. Nowhere and never before had complex treatment been brought directly to the combat line. This treatment, beginning with /466 the military region, provided the wounded patients with all forms of physiotherapy and exercise therapy -- those significant factors in pre-operative as well as post-operative treatment. Such early application of complex physiotherapy, its applicability at stages of evacuation, ensured 78.0% restoration of lost function in cases where operative intervention on the injured nerve trunks was not indicated.

The Soviet army's military field neurosurgery solved huge and complex problems presented by the war, and by its structured, correct organization and treatment principles based on modern scientific data, facilitated the restoration of lost function in peripheral nerve injuries (up to 90.0% restoration in injury to individual nerves), successfully provided all the conditions and possibilities for returning wounded soldiers to the ranks of our glorious unconquerable army, and enabled the overwhelming majority of these wounded (78.0%) to return to peacetime labor.

By its fruitful activity during the years of the Great Patriotic War, the medical service, including also neurosurgery, showed itself to be worthy of the heroic Soviet Army and the great Soviet people.

These remarkable results in the treatment of peripheral nerve injuries could be achieved because the army medical service was governed by the lofty Lenin-Stalinist ideals.
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