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MEDICAL DEPARTMENT, UNITED STATES ARMY

*SURGERY IN WORLD WAR II*

# HAND SURGERY

*Edited by*

STERLING BUNNELL, M. D.

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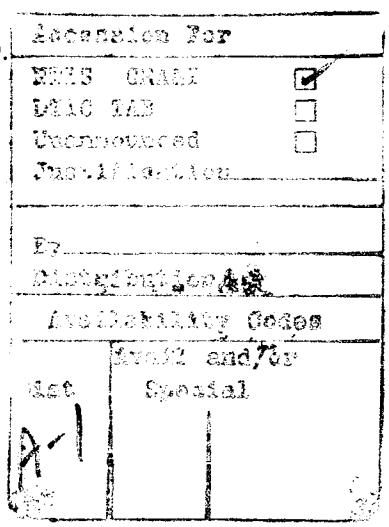
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THE MEDICAL DEPARTMENT OF THE UNITED STATES ARMY

# HAND SURGERY IN WORLD WAR II

*Edited by*

STERLING BUNNELL, M. D.


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This volume was prepared by the Historical Unit, Army Medical Service, under the direction of Colonel Calvin H. Goddard, MC, AUS, formerly Editor in Chief; Associate Editor for Hand Surgery, Mary E. McDonald; Assistant Editor, Janie W. Williams.

# Foreword

During the entire period of the War Between the States (1861–65), there were among Federal soldiers, 12,865 recorded cases of fractures of the bones of the hand and wrist due to shot injury. In addition, approximately 15,200 flesh wounds of the hand occurred. Hand wounds numbered approximately one-ninth of all those recorded in the Union Army; about 45 percent of them were complicated by fractures of wrist bones, carpals, or phalanges. Attention paid to hand injuries was slight in the official *Medical and Surgical History of the War of the Rebellion.* Only 6 pages deal with wounds and operations of the hand and an additional 24 pages discuss wounds and operations of the wrist.

Somewhat less than 300 lines cover the subject of hand injuries in *The Medical Department of the United States Army in the World War*, Volume XI, "Surgery," Part I, which present comparable studies for World War I.

Profiting from our experience of 1917–18, many surgeons began to devote increased attention to improving upon existing methods for the post-traumatic care of the hand. So keen did interest in hand conditions become that a number of "hand centers" were established during World War II in the United States and in Europe for the specialized treatment of the soldier who had received an injury to that extremity. True, many patients with hand wounds did not receive treatment in hand centers because their injuries were acquired before these were established and so were treated in general hospitals, or, because coexisting wounds of greater severity immobilized them on other surgical and orthopedic services. By reason of such factors, our World War II statistics on wounds of the hand could be more comprehensive. However, reports on treatment of hand wounds and on methods and procedures instituted for their care in hand centers are quite complete.

Many of the techniques, particularly for tendon repair and restoration of lost members or functions, were so successful as to evoke praise, not only from our own civilian surgeons, but also from their Allied colleagues. Scarcely a volume on hand surgery published abroad fails to make laudatory reference to one or more of those who are contributors to the present work. A survey of accomplishments of the hand centers leads to the conclusion that in event of another major military emergency, the Army Medical Service will find it expedient to give serious consideration to the re-establishment of a special "Hand Service" for the care of soldiers wounded in that extremity.

GEORGE E. ARMSTRONG
Major General, United States Army
*The Surgeon General*

# Preface

Much of the success achieved in World War II in salvaging crippled hands was due to the vision and initiative of the then Surgeon General, Maj. Gen. Norman T. Kirk. Precedent decreed that hand wounds be accorded routine surgical, or sometimes, orthopedic treatment. He determined to consider them a special group, worthy of segregation and treatment as such. By reason of his decision, there were established overseas various hand services, and in the Zone of Interior nine hand centers. The officers who staffed these also deserve their meed of recognition. Though overworked, they pioneered well in this new field of surgery. They proved conclusively that reconstruction of hands may successfully be undertaken and that crippled hands are worth salvaging.

Hands are of such major importance as to merit this belated attention. The hand is a regional or anatomic entity and its repair constitutes a special composite problem. Since it cannot be dealt with efficiently by any one of the three tissue specialty services its care must be entrusted to specially trained officers versed in all three—plastic, orthopedic, and neurosurgery. Experience has taught us that it is advantageous to have patients with injured hands assigned to general hospitals possessing all of these facilities, for the progress of each specialty is readily absorbed by those assigned to hand reconstruction.

During World War II hand surgery achieved considerable progress. Toward its close, patients treated in the Mediterranean and European Theaters of Operations were returned to the United States their hands healed and with cover. Indeed, some had been covered primarily by pedicle grafts in the first definitive treatment and were therefore limber. In the Zone of Interior a plan of action and approach was crystallized—the position of function was obtained by spring or elastic splints; new cover was applied; the skeleton realined; nerves and tendons repaired; and digits positioned and transferred, or rebuilt, to give sensation and prehension.

In the general plan of this volume the first chapter is by Col. Condict W. Cutler, Jr., MC, AUS, Surgical Consultant of the First Service Command. It covers the hiatus between the two World Wars. The second is a résumé by Sterling Bunnell, M. D., Civilian Consultant for Hand Surgery to the Secretary of War, of the work on reconstruction of hands. This is followed by an account of experiences in the Mediterranean Theater of Operations by Lt. Col. Harvey S. Allen, MC, AUS, and in the European theater by Col. Mather Cleveland, MC, AUS. Thereafter, each of the officers in charge of hand reconstruction in the nine hospitals in the Zone of Interior recounts the activities within his sphere of operation. There is, of necessity, some repetition, but it was felt best

to let each tell his own story, delineating his personal ingenuity and point of view. Taken together they present a better composite picture than could be achieved by a single author. That this method entails many difficulties can readily be understood; it is therefore, only fitting that we should mention some persons whose contributions were more than casual. The medical artists in the Armed Forces Institute of Pathology helped immeasurably on the many illustrations. The need for pictorial demonstrations in hand surgery is obvious, but since some in this volume were taken under highly adverse photographic conditions the skill of the artists was taxed to present them in the most favorable manner. The assistance to the editorial staff provided by Col. Ernest A. Brav, MC, Chief, Orthopedic Service, Walter Reed Army Hospital, is most gratefully acknowledged. The diligence of the research personnel in the Historical Unit in locating corroborative data on hand surgery can better be realized when it is recognized that such data did not appear under that title in reports and records but had to be extracted piecemeal from information on other specialties and sections.

In this volume we have attempted to record what has been learned in hand surgery so that such knowledge may be, and we hope will be, utilized in any future conflict.

STERLING BUNNELL, M. D.

San Francisco, Calif.
September 1954

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# *HAND SURGERY IN WORLD WAR II*

CHAPTER I

# The Overall Picture in the Zone of Interior

**Condict W. Cutler, Jr., M. D.***

In World War I, as in all earlier wars, no special consideration was given to the treatment of injured hands.[1] No distinction was made between these and other injuries, even though the hands were all-important to the future usefulness of the casualty himself as well as to the immediate possibility of his return to duty. Hand injuries were treated routinely by surgeons without special knowledge of hand surgery. Crippled hands were usually left that way. Very few were reconstructed, and those that were, were not adequately treated according to present standards.

Advances in surgery of the hand in the period between World War I and World War II can hardly be said to have kept pace with achievements in certain other fields of surgery. While striking progress was made in plastic and thoracic surgery, neurosurgery, and surgery of the stomach and intestines, and while increased knowledge concerning these specialties was quite widely disseminated among the profession, only a few were giving particular attention to surgery of the hand. Hand surgery was still considered minor surgery and the care of hand injuries and infections was left to general practitioners physicians in industrial plants and outpatient departments, and the younger members of hospital staffs.

Kanavel's book, *Infections of the Hand*,[2] had appeared during World War I. The sound teaching contained therein had received general recognition and wide acceptance, and had resulted in a better understanding and improved treatment of hand infections. This book remained almost the only standard text on hand care until the outbreak of World War II. During the intervening 25 years significant work in hand surgery was done by a few whose names constantly appeared and reappeared in the literature published on this subject. Notable among them were Sterling Bunnell in California, Deryl Hart in Durham, North Carolina, Henry Marble in Boston, also Hugh Auchincloss and Leo Mayer in New York. In Chicago Sumner Koch and Michael Mason, co-workers with, and successors of, Kanavel, continued his work and developed new procedures in reparative and reconstructive surgery of the hand, and Vilray P. Blair in St. Louis added notably to the development of plastic procedures.

*Assistant Clinical Professor of Surgery, College of Physicians and Surgeons, Columbia University. Formerly Colonel, MC, AUS.

[1] The Medical Department of the United States Army in the World War. Washington, Government Printing Office, 1927, vol. XI, pt. 1.

[2] Kanavel, Allen B.: Infections of the Hand. 1st ed. Philadelphia, Lea & Febiger, 1916.

Information on the subject was scattered in medical publications in this country and abroad. Textbooks carried sections on hand surgery which were usually incomplete, or, like Kanavel's book on infections, dealt with only a single phase of the subject. During this hiatus one book was published on hand care, a monograph by Marc Iselin [3] of Paris, onetime pupil of Sterling Bunnell. In 1942 Cutler's book [4] on the disabilities and diseases of the hand appeared. It was intended to serve as a guide in the diagnosis and proper treatment of injuries, infections, deformities, and tumors for surgeons who had not specialized in this particular field. Cutler's book represented the first attempt in this country to correlate the work of many surgeons who had had experience with these conditions. It was indicative of the emergence of surgery of the hand as a recognized field of specialized surgical endeavor.

Koch, Mason, and Allen had contributed to the development of hand surgery special methods of tendon suture, grafting, and restoration. They had evolved techniques of exposure and dissection for tuberculosis of the tendon sheaths. Their studies and original procedures in corrective splinting were significant contributions. Mason and Allen, in particular, had established the fundamental principles of tendon healing and Koch had shown the value of pressure dressings in burns. Auchincloss had carried to greater refinement Kanavel's anatomic concept of hand infections, particularly in studies of the anatomy of the fingers. Mayer had developed reconstructive surgery of the joints and tendons of the hand. Bunnell had perfected the wire pullout stitch for tendon repair and had clarified the importance and feasibility of peripheral nerve repair in the hand and fingers. From 35 years' work in this special field, he had acquired and demonstrated an almost unique skill and ingenuity in the intricate and formidable reconstruction of even the most disabling and deforming lesions.

Except for the work of these and a few other surgeons, little such hand surgery was being done at the outbreak of World War II. Kanavel's principles concerning the management of infections were accepted and generally taught, although they were by no means universally employed. Except in large hospitals and in clinics, acute injuries of the hand were managed by many practitioners in a manner which left much to be desired. The results of early tendon repair, especially of the flexor tendons, were deplorable. Flat splinting of fractures was still quite prevalent. When skeletal traction was employed the principles of traction splinting were often imperfectly applied. The importance of the position of function [5] when immobilization was necessary was not generally recognized. Burns were still treated without due regard for asepsis,

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[3] Iselin, Marc: Chirurgie de la Main: Plaies, Infections, Chirurgie Réparatrice. Paris, Masson et Cie., 1933.

[4] Cutler, Condict W., Jr.: The Hand: Its Disabilities and Diseases. Philadelphia, W. B. Saunders Company, 1942.

[5] See Chapter II, p. 24.

tanning agents were often applied, and the denuded areas that burns produced were far too often allowed to heal by granulation and slow epithelization. Early skin coverage was far too seldom utilized. Corrective splinting and physical and occupational therapy for the restoration of function were still inadequately used or completely ignored.

The result of these concepts and practices was a large number of crippled and deformed hands which might have been prevented or greatly ameliorated by skilled attention. When to these disabilities the injuries of war were to be added, there was in prospect a situation which threatened great loss of manpower and much individual incapacitation. Yet thanks to the work, investigation, and teaching of a relatively few men, there was a reservoir of knowledge and skill whence came guidance to others in the treatment of the inevitable hand injuries of production and war.

## HAND IMPAIRMENTS AS AN INDUCTION FACTOR

In the general evaluation of hand impairments as an induction factor during World War II, the disabilities which were of a disqualifying nature with respect to acceptability for military service will be considered first. According to the mobilization regulations (MR 1–9, Standards of Physical Examination During Mobilization, dated 19 April 1944) that governed the determination of fitness for military service in World War II, individuals with the following hand defects were considered nonacceptable: Loss of 1 or both thumbs or loss of more than 2 entire fingers of either hand. Detailed diagnostic data collected by the Medical Statistics Division, Office of The Surgeon General, for the period from November 1943 through December 1944, indicate that 487 per 100,000 registrants examined for military service were disqualified during this period for hand impairments by the local boards and induction stations combined (Table 1). In addition to these, there were other registrants who were disqualified for more serious conditions who had hand impairments of a disqualifying nature as well (Table 1). All in all, the experience of World War II indicates that between 0.5 and 0.6 percent of the examined registrants had a hand impairment of a disqualifying nature.[6]

A diagnostic breakdown of the impairments is presented in Table 1. As shown in the table, these disqualifying impairments were primarily amputated fingers.

These figures gain significance in the light of the rather liberal attitude of the Army toward the acceptance of soldiers with hand defects. According to the Standards of Physical Examination During Mobilization,[7] loss of 1 or both thumbs, or loss of more than 2 entire fingers of either hand was the only cause for rejection on the basis of hand defects. Acceptable for limited service

[6] These rates exclude such general conditions affecting the hand as tumors, osteomyelitis and other bone or joint conditions, muscular disorders, skin diseases including tuberculosis, etc.

[7] MR 1–9, 19 Apr 44.

TABLE 1. PREVALENCE OF DISQUALIFYING HAND IMPAIRMENTS AMONG REGISTRANTS PROCESSED FOR MILITARY SERVICE, 1 NOVEMBER 1943 TO 31 DECEMBER 1944*

| Impairment | Rates per 100,000 registrants examined | |
|---|---|---|
| | Principal disqualifying defect | Total disqualifying defects |
| Amputation, wrist | 25 | 25 |
| Amputation, fingers | 223 | 260 |
| Ankylosis, wrist | 6 | 6 |
| Ankylosis, hand or fingers | 14 | 18 |
| Limitation of motion, wrist | 24 | 29 |
| Limitation of motion, hand or fingers | 77 | 101 |
| Arthritis, wrist | 9 | 10 |
| Arthritis, hand or fingers | 8 | 9 |
| Deformity from fracture, forearm or wrist | 26 | 30 |
| Deformity from fracture, hand or fingers | 5 | 8 |
| Deformity, congenital, forearm or wrist | 4 | 5 |
| Deformity, congenital, hand or fingers | 21 | 25 |
| Ganglion, wrist | 3 | 4 |
| Other deformities, wrist | 7 | 7 |
| Other deformities, hand or fingers | 35 | 46 |
| Total | 487 | 583 |

*Sample tabulations of "Report of Physical Examination and Inductions" (DSS Form 221). Rates include both disqualifications by the local boards and at the induction stations.

were men who had lost 2 entire fingers of either hand, except a combination of the right index and middle fingers; those who had webbed fingers even if severe in degree, or those with moderate deformities which had not interfered with function to a degree which had prevented the individual from following a useful vocation in civil life. Acceptable for general service were candidates presenting such defects as webbed fingers unless severe in degree; entire loss of the little finger of either or both hands, or the ring finger of the left hand; loss of the terminal phalanx of the right index finger; loss of the terminal and middle phalanges of 1 finger, except the right index finger, on 1 or both hands; loss of 1 phalanx of 1 or all fingers on 1 or both hands provided the function of the hand was ample to permit the performance of general military duty. Scars and deformities of moderate degree which permitted normal function did not cause rejection.

Among the registrants found acceptable, 1.7 percent had a hand impairment of a nondisqualifying nature (Table 2). This rate includes both registrants found acceptable for general or limited service. These were also inductees who had more than 1 hand impairment. Altogether, the prevalence rate of hand impairments among acceptable registrants was about 22 per 1,000

TABLE 2. PREVALENCE OF NONDISQUALIFYING HAND IMPAIRMENTS AMONG REGISTRANTS FOUND ACCEPTABLE FOR MILITARY SERVICE, 1 NOVEMBER 1943 TO 31 DECEMBER 1944*

| Impairment | Rates per 100,000 registrants found acceptable | |
|---|---|---|
| | Principal nondisqualifying defect | Total nondisqualifying defects |
| Amputation, wrist | | |
| Amputation, fingers | 589 | 737 |
| Ankylosis, wrist | 2 | 2 |
| Ankylosis, hand or fingers | 53 | 68 |
| Limitation of motion, wrist | 62 | 75 |
| Limitation of motion, hand or fingers | 585 | 751 |
| Arthritis, wrist | | 1 |
| Arthritis, hand or fingers | 3 | 4 |
| Deformity from fracture, forearm or wrist | 83 | 112 |
| Deformity from fracture, hand or fingers | 57 | 73 |
| Deformity, congenital, forearm or wrist | 1 | 1 |
| Deformity, congenital, hand or fingers | 40 | 56 |
| Ganglion, wrist | 41 | 57 |
| Other deformities, wrist | 24 | 27 |
| Other deformities, hand or fingers | 170 | 217 |
| Total | 1, 710 | 2, 181 |

*Sample tabulations of "Report of Physical Examination and Induction" (DSS Form 221).

acceptees. Amputated fingers and limitation of motion of hand and fingers were the primary impairments.

The validity of provisions of MR 1–9 with respect to hand impairments was later amply demonstrated in the performance of varying types of service by soldiers with such impairments. It was rare to find that a lesion of the hand, permitting induction, resulted in later incapacitation of the soldier for the type of duty for which he had been accepted. Separations and reclassifications on this basis were few.

## TRAINING PERIOD EXPERIENCES WITH NONCOMBAT-INCURRED HAND INJURIES

It was reasonable to expect that soldiers in training would be subject to the same injuries and infections of the hand they commonly encountered in civil life. That the hazards of the training program involving unaccustomed manual labor, the use of unfamiliar implements and weapons, and the rigorous schedule of physical training would tend to increase the incidence of injuries was foreseen. The records of the station hospitals of the training camps bore out this prediction.

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### *Infections*

Often encountered were infections of the hand resulting from minor wounds, blisters, and splinters. These were sufficiently numerous to cause some concern. Delayed and inadequate incisions resulted in severe involvement of tendon sheaths and tissue spaces. Most men with hand infections were hospitalized early and received satisfactory care. At first, however, there was a tendency to treat many of them in dispensaries on an ambulatory basis, a plan which proved entirely unsatisfactory because of the apparent lack of experience of many dispensary physicians dealing with these conditions. It was not until mid-1945 that all men with acute hand infections were required to be hospitalized immediately, and policies and principles for management of hand infections established.[8] Protection against infection in all open wounds was managed by routine administration first of sulfanilamide, then of sulfadiazine,[9] and later of penicillin. The use of sulfanilamide in wounds, at first strongly recommended,[10] was eventually discarded as ineffectual.[11]

In May 1944 *The Bulletin of the U. S. Army Medical Department* [12] stated:

> The exact status of chemotherapy has not been completely established. It may be justifiably stated, however, that in the light of recent critical studies and more extensive experience the widely heralded and perhaps over-enthusiastic concept regarding the value of sulfonamides in wound infection must now be considerably modified. Whereas many surgeons continue to frost the wound with sulfanilamide, the beneficial effects of the drug, when applied locally, are questioned by careful observers. The critical surgeon, in our Army and in the British Army, is beginning to veer away from the local use of sulfonamides and to rely on their systemic effect to prevent general sepsis and spreading infection. For this reason it is recommended that sulfadiazine, which is considered the drug of choice, be administered by oral or parenteral means at the earliest opportunity after injury and continued postoperatively. At present, penicillin appears to be the most promising bacteriostatic agent in controlling wound infection. It seems to have great potentialities in military surgery.

That penicillin and later antibiotics would run a similar gamut of acceptance and rejection in local application to open wounds was reflected in the report of the Surgical Consultant to the Ninth Service Command: [13]

> With the advent of penicillin the same enthusiastic acceptance was demonstrated throughout the Army and it was felt that at last a drug had been found which assured complete protection against the hemolytic streptococci and many other organisms. Enthusiasm became so rampant that in many instances throughout the general hospitals the sulfonamides and penicillin were used concomitantly and reports began appearing

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[8] Acute infections of the hand. Bull. U. S. Army M. Dept. 4: 100–104, Jul 1945.

[9] SG Ltr 164, 28 Nov 42, sub: Issue of individual packages of sulfadiazine in lieu of sulfanilamide tablets to military personnel in theaters of operations.

[10] Prevention of infection in wounds and burns. Prepared under auspices of NRC Committee on Chemotherapeutic and Other Agents and NRC Committee on Surgery. War Med. 2: 488–496, May 1942.

[11] TB Med 147, Mar 1945, sub: Notes on care of battle casualties.

[12] War wounds of the extremities. Bull. U. S. Army M. Dept. No. 76, May 1944, p. 61–71.

[13] Beaver, M. G.: Surgical consultant's history, 1 Feb 45 to 15 Oct 45, Ninth Service Command, p. 92–93. HD: 314.7–2.

indicating that by the use of these drugs together almost complete protection was given against any type of infection. With more experience and more time to evaluate these drugs, the following conclusions were finally arrived at:

At the present time there are no antibacterial chemotherapeutic agents which, when put into wounds will be of value in preventing suppuration. . . . Both penicillin and the sulfonamides, when administered systematically, will inhibit the action of the hemolytic streptococci, the hemolytic staphylococci and the clostridial organisms. No antibacterial agents are ever inserted into a wound with the possible exception that liquid penicillin may be put into serous cavities and major joints as a complement to further surgical procedures.

The new drug, streptomycin, is still in its experimental stage and experience with it in the Army is still very limited. Five hospitals in this command have been designated for its clinical evaluation and if it proves to be as effective as the advance notices have given it credit, it undoubtedly will be a valuable adjuvant to the armamentarium of the surgeon.

As the result of observation in the Zone of Interior, and later in overseas areas, The Surgeon General had reviewed the salient points of the treatment of infections of the hand for the benefit of those officers whose experience in dealing with these conditions was limited. A special article, prepared by the Surgical Consultants Division of the Surgeon General's Office, was published in *The Bulletin of the U. S. Army Medical Department* in 1945.[14] This article, well illustrated with diagrams indicating the major tissue spaces of the hand and the appropriate incisions to be made for draining them, stated the policies and principles established by the Medical Department for the management of hand infections, as follows:

Acute infections of the hand are of importance, both in theaters of operations and in the zone of the interior. They are a source of significant numbers of temporary and even permanent disabilities. Prompt recognition followed by correct evaluation and adequate treatment is essential if noneffectiveness and loss of function resulting from these conditions are to be reduced to a minimum. Surgical drainage of the infected hand should be the responsibility of the most experienced surgeon available.

The *diagnosis* of the presence of an acute infection of the hand can be made easily. The patient usually presents himself because of the pain in the part and other characteristic signs and symptoms of inflammation. Exact diagnosis of the tissue space or spaces involved, however, can only be made by one having a thorough knowledge of the anatomy of the hand. Careful inspection followed by precise palpation should be meticulously and gently performed in every case. Of paramount importance in every case of hand infection is a complete clinical examination of the deep fascial spaces, the tendon sheaths, and radial and ulnar bursae, in order that the extent of the infection will be well understood prior to surgery.

Certain *general therapeutic principles* should be applied in all cases of acute hand infection, regardless of the space or spaces involved. These may be collocated as follows:

1. All patients with acute infections of the hand should be promptly hospitalized.

2. As soon as the diagnosis has been established, *adequate surgical drainage* of the involved space or spaces should be performed immediately. Conservative measures, e. g.,

[14] See footnote 8, p. 8.

hot packs and hypertonic saline soaks employed in lieu of adequate drainage, are frequently responsible for extension from one involved space to the other.

3. The dissection should be of an unhurried, deliberate, and precise character. Thus, the routine use of *general anesthesia* is essential. A bloodless field made possible by the use of a *tourniquet* further contributes to the performance of an accurate dissection which opens only the involved space or spaces.

4. Postoperatively, efficient immobilization of the affected extremity in the position of maximum function by means of a voluminous dressing is of extreme importance.

5. Confinement in bed, with the affected part elevated above heart level by pillows, should be a routine order in all cases.

6. Drains should be prepared of dry or petrolatum fine mesh gauze. They should be introduced so as to prevent agglutination of raw wound surfaces. They should never be "packed" in place or come in direct contact with nerves or tendons.

7. Penicillin in dosages of 200,000 units or more every twenty-four hours should be administered systemically until the infection has subsided. The local application of chemotherapeutic agents is not advocated.

### Injuries

Accidents incidental to the training program and involving the hand were numerous. They consisted of lacerating and crushing injuries, traumatic amputations of fingers, burns, gunshot wounds (often producing compound fractures of the metacarpals as well as associated injuries of the soft parts), mutilating wounds from hand grenade explosions, and simple fractures.

In the management of the most destructive types of injuries surgeons were guided by the principle of tissue conservation.[15] Under the direction and instruction of surgical consultants of the service commands it came to be understood generally that such wounds were to be treated according to strict surgical principles, with particular regard for preservation of as much tissue as possible consistent with safety. Open wounds were to be carefully cleansed and freed of devitalized tissue and foreign bodies and, if contamination was severe, were to be left open for subsequent dressing and healing. In a few favorable cases, when contamination was minimal and the patients were seen within a few hours after injury, primary repair was permissible. Primary repair of divided flexor tendons within the digital canals, however, was not approved because of the generally unfavorable results of immediate suture; these injuries were subjected to formal repair only after complete, clean healing had been achieved.

### Burns

After gentle cleansing, burns were generally treated by the application of vaseline gauze and pressure dressings. This treatment, followed by noninterference with the initial dressing for 10 to 14 days, and subsequent care under aseptic precautions, found ready acceptance because of the satisfactory results obtained. The importance of coverage of these and other open hand wounds

[15] Cutler, C. W., Jr.: Early management of wounds of the hand. Bull. U. S. Army M. Dept. No. 85, Feb 1945, p. 92–98.

by early application of skin grafts was constantly emphasized.[16] The split thickness graft obtained with Padgett's dermatome was quite generally and satisfactorily employed.

### *Wounds Involving Bone*

In these wounds, as well as in simple fractures of the metacarpals and phalanges, skeletal traction was generally used,[17] its proper employment guided by the consultants. In all hands requiring immobilization the importance of the position of function was stressed. Constant, unremitting attention to this detail was required as the tendency was to employ traction in the extended position. Another tendency, which required correction, was the extension of plaster casings applied for other injuries of the upper extremity beyond the distal palmar crease, unnecessarily restricting finger motion.

### *Traumatic Amputations*

Traumatic amputations of the fingertips in training were the result of catching digits in pulleys and breech blocks, in doors or hatches of tanks, and under heavy objects. In some, formal reamputation with flap formation had to be employed, but as a rule a more conservative attitude was adopted and encouraged. In 1942 Terhune and Camp [18] reported on a group of such cases seen in the station hospital, Camp Polk, Louisiana. Debridement, cleansing, and immediate split thickness or pinch grafting of the open traumatic stump of the distal phalanx were successfully practiced. The wounds were treated locally with sulfanilamide and pressure dressings were left undisturbed over the graft for 8 days. The edges of the graft had been secured to the skin margins of the finger by interrupted sutures using No. 0 black silk and a small curved cutting needle. The graft was not sutured to the dorsal margin of the stump, nor was any of the nail bed covered.

All of the discharged patients were returned to duty with only a minimal amount of disability and capable of the same physical performance as before the accident.

### *"Baseball Fingers"*

Notable among training period injuries were "baseball fingers" usually acquired in playing softball. Disruption of the attachment of the extensor tendon to the distal phalanx was treated by splinting in the hyperextended position either with a plaster of paris or a Lewin-type metallic splint.

### *Carpal Bone Fractures*

Fractures of the carpal bones, especially the carpal navicular bone, followed falls on the hand. In the earlier days of the war these fractures frequently

[16] TB Med 151, Mar 1945, sub: Surgical management of thermal burns.

[17] TB Med 133, Jan 1945, sub: Suspension-traction treatment of fractures.

[18] Terhune, S. R., and Camp, M. C.: Traumatic amputation of the finger tips. South. Surgeon 11: 646–651, Sep 1942.

escaped attention; in many instances they passed as "sprained wrist." Until surgeons at station hospitals were alerted to the frequency of its occurrence, appropriate treatment was often delayed by failure to recognize this injury. In all cases of wrist injury it became the practice to require oblique as well as lateral and anteroposterior roentgenograms. When this was done and four roentgenograms made, many fractures which would otherwise have escaped detection were revealed.

A typical report on carpal navicular fractures treated at a station hospital in a training area was made by Allen.[19] In a 6-month period, ending 20 January 1943, 6 such fractures were discovered in 57 roentgenograms of the wrist, while 3 additional, all unsuspected, were found in 150 roentgenograms of the hand taken to reveal fractures of the long bones. A correct diagnosis on clinical findings had been made in only 1 of these 9 cases. The injuries Allen reported were sustained chiefly in sports—football, baseball, basketball, and wrestling.

Carpal navicular fractures were immobilized in plaster casings for periods of 8 to 12 weeks. The casing was applied from the distal palmar crease nearly to the elbow, with the thumb included to the base of the distal phalanx. The first metacarpal was placed in hyperextension with moderate radial flexion of the wrist and with the hand in the position of function. This method succeeded in assuring bone union in the majority of cases. Relatively few patients subsequently required either removal of the navicular fragment or peg-bone grafting for nonunion. It was noted that prolonged immobilization in the position of function did not result in stiffening of the hand or wrist joints. Immobilization was well tolerated by the patients and, after removal of the casing, full motion was rapidly and readily restored.

The most serious injuries of the hand acquired in training were gunshot and explosive wounds, crushing wounds, and amputations. They differed in no essential particular from those encountered later as the result of combat. Early treatment and subsequent reconstructive surgery followed the pattern used for combat casualties, and are fully considered in later chapters.

## ESTABLISHMENT OF FACILITIES FOR SPECIALIZED CARE OF HAND INJURIES

A short time after the arrival of the first battle casualties from foreign theaters and their distribution to the general hospitals in the Zone of Interior, it became apparent that injuries of the extremities would comprise a high percentage of battle wounds. Various estimates placed the incidence of these wounds at from 65 to 70 percent of all wounds received in combat areas.[20] Among them, injuries involving the hand were numerous. A variety of lesions

[19] Allen, W. E., Jr.: Fracture of the carpal navicular. Mil. Surgeon 93: 464–467, Dec 1943.
[20] See footnote 12, p. 8.

were encountered, including burns, both healed and unhealed; injuries of soft parts involving tendons, nerves, and intrinsic muscles; compound fractures of bones of the wrist and hand, some associated with osteomyelitis, others showing nonunion, malunion, or loss of bony substance; mutilating injuries with loss of parts ranging from absence of part of a digit to almost complete amputation of the hand. There was almost every imaginable combination of these injuries. Moreover, many injuries of the upper extremity—injuries of the radial or ulnar nerves, fractures of the bones of the forearm, atrophy and stiffening following immobilization, and in a few cases Volkmann's contracture—produced deformity or disability of the hand.

### *Early Disposition of Hand Injuries*

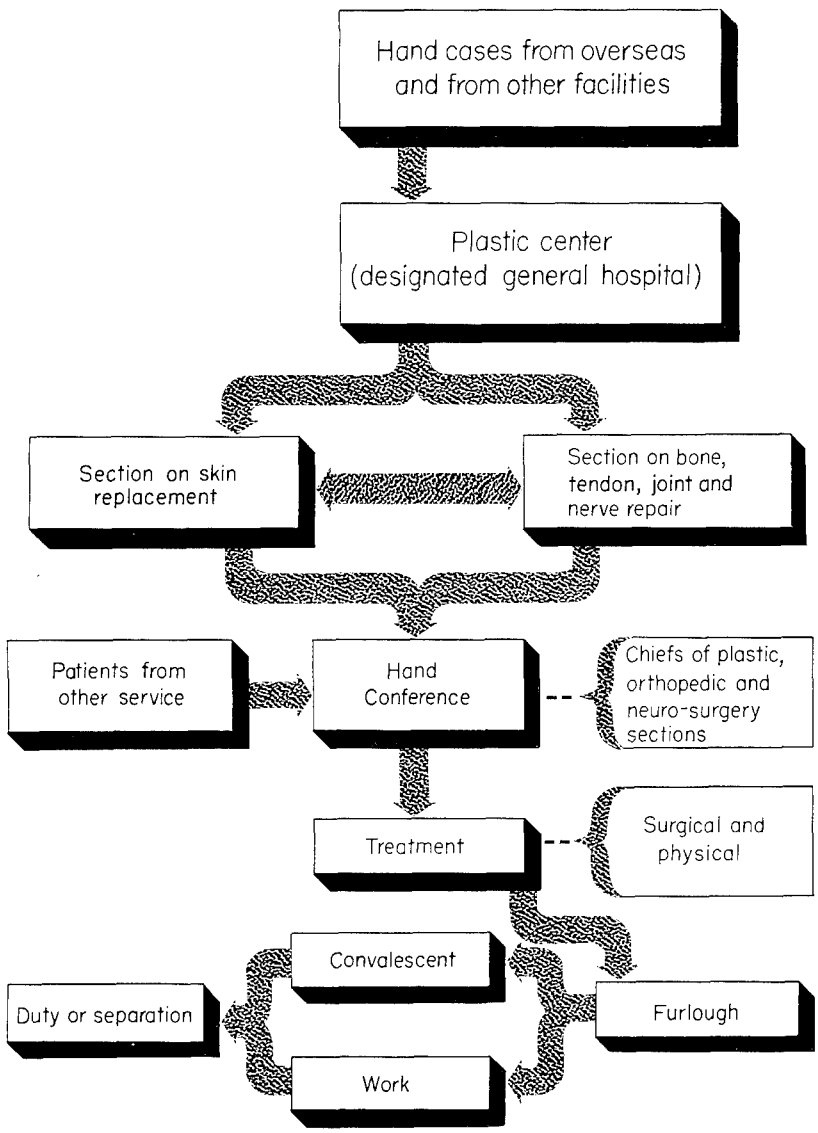
Patients with these disabilities were at first placed in the individual hospitals, in the wards of the orthopedic sections, the sections of general surgery, or—where they existed—in the sections of plastic surgery or neurosurgery. Thus, in any one hospital, hand cases might be found in several sections, in various wards, and under the care of half a dozen different men. To those interested in hand surgery the disadvantages of this situation were apparent. Since the structures of the hand are so closely interrelated and injuries inevitably involve several or all of its structures, their repair would require the services of several specialists at the same time. Obviously, the effective management of a disabling hand injury could not be accomplished by the employment of the services of several specialists one after another. The practical solution was to consider reconstructive surgery of the hand as a specialty in its own right. This concept required the provision and training of men who could treat the hand as an entity, and who were equipped to deal with the orthopedic, plastic, and neurosurgical problems encountered in this restricted field. These men must be prepared to evaluate the needs of each individual case, to plan the therapy, and to carry it through to conclusion. Essential to the success of this plan was the segregation of hand patients within the hospital in special wards under the care of the hand surgeon and his assistants.

In accordance with this plan, permission was secured from Col. J. J. Reddy, MC, First Service Command Surgeon and from Col. F. V. Kilgore, MC, Commanding Officer, Cushing General Hospital to establish a ward in that hospital designated specifically for the care of injuries of the hand. To this ward was assigned a surgeon, Capt. (later Maj.) J. William Littler, MC, who was to be given control and supervision of the treatment of all hand injury patients. At first, the assistance of the orthopedic, plastic, and neurosurgeons at that hospital was secured to aid and guide this officer in the technical performance of the necessary bone work, plastic procedures, and nerve repair. A series of conferences was set up for diagnosis, evaluation, and discussion of problem cases of hand reconstruction, attended by these specialists, the surgical consultant, and the officer in charge of the hand surgery service. As a result of these combined efforts, the latter officer rapidly acquired the technical skill

required to perform, unaided, the procedures recommended in these conferences. It soon became necessary to enlarge the service to two full wards, and eventually a third and fourth ward was added.

When this service was in satisfactory operation, its organization (Chart 1) and procedures were communicated to The Surgeon General, and it was recom-

CHART 1. SCHEME OF ORGANIZATION AT CUSHING GENERAL HOSPITAL FOR MANAGEMENT OF HAND CASES WITHIN PLASTIC SURGERY CENTER.



mended by the First Service Command Surgical Consultant that similar centers for the care of injured hands be established in each service command. Following inspections at Cushing, first by Col. B. N. Carter, MC, Assistant Director, Surgery Division, Office of The Surgeon General, and subsequently by Maj. Gen. Norman T. Kirk, The Surgeon General, this recommendation was approved and all of the plastic centers and certain of the general hospitals in the Zone of Interior were designated as reception centers for care of hand injuries.

### *Plastic Surgery Centers Designated to Receive Hand Surgery Cases*

In the Army Medical Corps there was not a sufficient number of medical officers trained in the special surgery of the hand to provide a surgeon of adequate skill and experience for each general hospital. There were, however, enough men who had been trained in the clinics of Bunnell, Koch and Mason, and Marble to form a nucleus for this special service. It was decided to place these men in certain hospitals in each service command and to establish under them special sections for hand surgery to which all serious cases in this field should be assigned. The general hospitals assigned to receive hand surgery cases were Cushing, Valley Forge, Northington, Wakeman, Baker, Crile, O'Reilly, Beaumont, and Dibble.[21] [22] [23]

### *Assignment of Patients*

As a result of the experience following the issuance of the directive designating hospitals for specialized care, The Surgeon General established this policy governing the disposition of patients with hand injuries which was set forth as follows in a statement published in *The Bulletin of the U. S. Army Medical Department* for May 1945:[24]

> Patients who require extensive reconstructive surgery of the hand present a problem in plastic, orthopedic, and neurosurgery and require the attention of surgeons with special training and experience in hand surgery. While hospitals are not being designated as hand centers, the existing centers for plastic surgery are considered as appropriate hospitals for these cases, and properly qualified surgeons are being assigned to them where necessary to supplement the present staff; therefore, the more complicated hand cases should be transferred to centers for plastic surgery where reconstructive surgery of a complicated nature is to be performed.
>
> The selection of cases for transfer, will, in doubtful cases, be left to the discretion of the commanding officer and service command surgeon. It is difficult to establish detailed rules for the transfer of these cases and, furthermore, complicating conditions such as

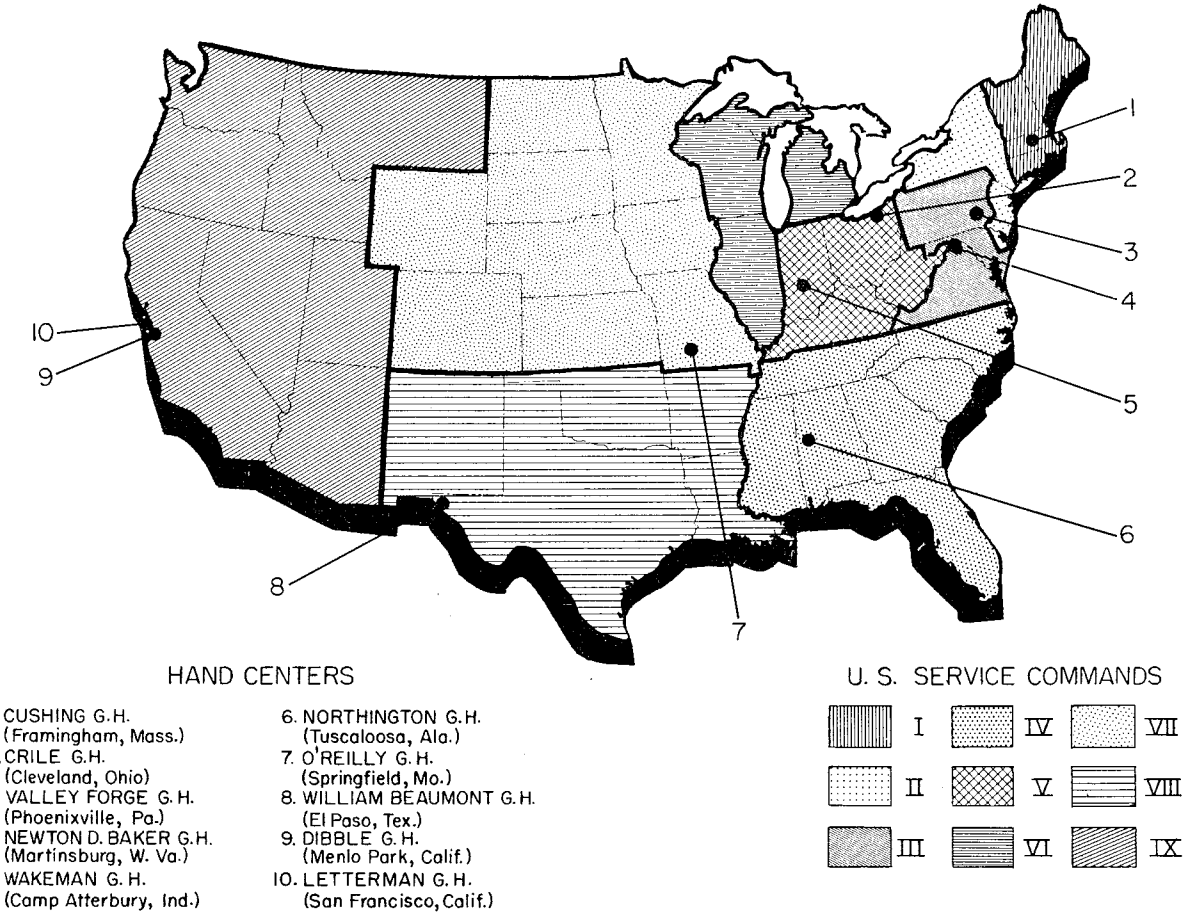
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[21] The general hospitals named, with the exception of Crile, were designated as plastic surgery centers by WD Circular 347, section 1, subject: General hospitals designated for specialized treatment, 25 Aug 44.

[22] Crile General Hospital plastic surgery center was activated 12 Feb 45 (Annual Rpt, Crile Gen Hosp, 1945. HD).

[23] Letterman General Hospital was designated a plastic center 28 May 43 (AG Memo 40-14-43). Its plastic surgery patients were transferred to Dibble General Hospital by letter of 31 May 44 (CG ASF (SG) to CG 9th SvC, 31 May 44, sub: Transfer of specialized facilities. SG: 323.7-5).

[24] Special hospitals for hand surgery. Bull. U. S. Army M. Dept. No. 88, May 1945, p. 2.




*Map 1. Hand Centers, Zone of Interior.*

amputations, deafness, and chest or vascular lesions may require specialized treatment of high priority.

A moot point concerning jurisdiction where more distant lesions involved the hand secondarily was met in the same article by the following statement:

Hand disabilities due to severance of major nerve trunks, but which have not suffered direct hand trauma, are considered neurosurgical in nature and the necessary treatment will be carried out at the appropriate center.

It was foreseen that the rapid increase in the number of cases of hand injury would seriously overtax the facilities of the plastic centers, and the article went on to say:

The less extensive types of hand surgery such as those involving only skin or tendon or bone and limited to one or two digits may be treated in regional and general hospitals not designated as plastic surgery centers, at the discretion of the service command surgeon.

### *Management of Centers*

Various methods of local management were employed within the plastic centers especially designated for the reception of patients requiring formidable reconstructive surgery of the hand. At Wakeman General Hospital there were separate wards for hand patients under the plastic section; this was also the arrangement at Crile and Beaumont. At Dibble General Hospital the hand section was originally under the plastic section, but subsequently became a subsection of orthopedics. At Valley Forge General Hospital the hand patients were distributed in several orthopedic wards but were under the care of a single surgeon in the orthopedic section. At O'Reilly the patient was placed in the particular surgical section on which the first phase of treatment was to be instituted.

At Northington and Baker General Hospitals, as at Cushing General, separate and independent sections for hand surgery were developed, a plan for the management of these cases which presented certain distinct advantages. It permitted the close integration of problems of a similar type and provided opportunity for consistent management of cases and for the training of surgeons in this special field, advantages not afforded by other arrangements. Inherent in such a plan was supervision by a well trained and highly experienced surgeon equipped to undertake formidable reconstructive surgery of the hand and prepared to deal with plastic, orthopedic, and neurosurgical aspects.

### *Appointment of Civilian Consultant*

In order to guide, integrate, and develop the special field of hand surgery, The Surgeon General, in October 1944, requested that Sterling Bunnell, M. D., of San Francisco be designated as special civilian consultant to the Secretary of War, under authority of Public Law 374, 78th Congress. The request was

approved the same month; Dr. Bunnell was appointed 2 November and entered upon his duties 29 November 1944.[25] Almost at the same time Bunnell's monumental work, *Surgery of the Hand*,[26] was published. This book was adopted as an official text by the Army [27] and distributed to all hospitals.

In November 1944 Dr. Bunnell began the first of a series of eight tours throughout the Zone of Interior. In the course of the succeeding 2½ years, he visited most of the general hospitals in the United States. At each he surveyed the problems and procedures of hand surgery, evaluated the qualifications of the medical officers assigned to this work, and gave active consultation on individual cases. He conducted clinics, rounds, and roundtable discussions, operated on a number of patients for demonstration of his methods, and conducted intensive 3- to 4-day courses on the diagnosis and management of hand lesions.

These visits, and the reports to The Surgeon General which followed (see Chapter II), resulted in a great stimulation of interest in the problems of hand surgery, in improved management policies at the various hospitals, and in a wide diffusion of technical knowledge among the medical officers concerned.[28]

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[25] Reports to The Surgeon General from the Civilian Consultant for Hand Surgery to the Secretary of War. HD: 730.

[26] Bunnell, Sterling: Surgery of the Hand. Philadelphia, J. B. Lippincott Company, 1944.

[27] Standard Item No. B718390, Section 2, Change 1, Med 3, Medical Supply Catalog (Bull. U. S. Army M. Dept. No. 85, Feb 1945, p. 21).

[28] Annual Rpt, Surgical Consultants Div, 1945. HD.

CHAPTER II

# Conclusions on the Care of Injured Hands in World War II Derived From the Experiences of the Civilian Consultant for Hand Surgery to the Secretary of War

*Sterling Bunnell, M. D.**

By November 1944 many patients with crippled hands were scattered throughout the general hospitals in the Zone of Interior. Most of them had had no reconstructive operations and since a knowledge of hand reconstruction was not widespread, there was no very clear understanding of how to approach the problem. Most of the wounds had been closed, but many hands were functionless because they had been incorrectly splinted and had become stiffened in positions of deformity, while many others showed bony malunion and nonunion.

When late in the year 1944 The Surgeon General directed his attention to the problem of hand injuries, casualties with such injuries were, for the first time in any war of history, segregated and given special consideration.

## INCIDENCE [1]

Complete statistics concerning the number of hands injured in World War II are not available. However, a rough estimate based on the number of injuries observed in general hospitals in the Zone of Interior can be made. Between June and October 1945, 4,542 hand injuries were counted at various times in the nine hand centers (Table 3). During the hand center operation period, there was probably at least one turnover of patients which would increase this figure to about 9,000. Only the most severe injuries were sent to hand centers and those who had sustained multiple wounds in addition to their hand injuries were scattered throughout the 54 other general hospitals and the many regional and station hospitals in the Zone of Interior. These were estimated to number 6,000. It was also assumed that approximately 400 patients with lesions of the nerves of the arm which resulted in crippled hands must have been treated in each of the 19 neurosurgical centers. This group would number about 7,600. Thus, on the basis of the writer's calculations, a conservative figure for the total number of injured hands treated in hospitals in the Zone of Interior in World War II would be 22,000.

It is further estimated that of the 592,170 wounded and injured in action cases in the Army, about 25 percent of the wounds, or 148,042 were of the upper

*Consultant in Surgery to the United States Army and to the United States Navy.

[1] For a discussion on incidence of hand injuries see the Foreword.

TABLE 3. HAND INJURIES DURING PEAK PERIOD, JUNE TO OCTOBER 1945, IN THE NINE HAND CENTERS IN THE ZONE OF INTERIOR

| Month | Hospital | Patients | Operations | Officer in charge |
|---|---|---|---|---|
| June | Wakeman | 300 | 90 | Maj. Lot D. Howard, Jr. |
| June | Crile | 280 | 100 | Maj. Gilbert Hyroop. |
| August | Beaumont | 787 | 116 | Lt. Col. William H. Frackelton. |
| August | Northington | 550 | 130 | Maj. Arthur J. Barsky. |
| August | O'Reilly | 500 | 130 | Maj. George S. Phalen. |
| October | Dibble | 850 | 55 | Maj. Donald R. Pratt. |
| October | Cushing | 305 | 40 | Capt. James W. Littler. |
| October | Valley Forge | 450 | 160 | Maj. Walter C. Graham. |
| October | Baker | 520 | 112 | Maj. Samuel B. Fowler. |
| Total | | 4, 542 | 933 | |

extremities, and that 15 percent, or 88,825 affected the hand. (This estimate includes injuries of the nerves of the arm and forearm which may affect the hand quite as seriously as direct hand injuries.) On the assumption that three-fourths of the men with hand injuries would be returned to duty, the number of these injuries accumulating in the hospitals in the Zone of Interior would be in the neighborhood of 22,000.

## OBSERVATIONS ON ORGANIZATION OF SPECIAL HAND SERVICES

Early in 1945 instructions were issued that all casualties with serious hand injuries should be concentrated in the nine general hospitals in the Zone of Interior already designated as plastic surgery centers.[2] It was the conviction of the Consultant for Hand Surgery to the Secretary of War that the management of hand injuries in a plastic surgery center did not fully meet the situation any more than the assignment of these patients to an orthopedic surgical center or a neurosurgical center would have met it. He believed that hand surgery should be carried out on a special service devoted to such surgery. He was convinced that the surgeon responsible for the hand should control the composite situation, unhampered by anatomic limitations, so that he might approach the problem from the functional standpoint. The hand surgeon must work from the elbow down in 3 overlapping specialities: Plastic, orthopedic, and neurosurgery. The hand is so intricate in structure that if dissected in turn by 3 different specialists it is likely to be wrecked beyond repair. The bones, joints, muscles, tendons, nerves, and skin are all parts of a composite mechanism in the function of the hand and they can best be repaired by the surgeon who

[2] See Chapter I, p. 15.

assumes responsibility for the whole. Hand surgery is an area speciality, not a tissue specialty.

Without doubt the plastic surgeons in World War II did exceptionally good work, but plastic surgery of the hand necessitated a concept which included more than the mere covering of defects. Some plastic surgeons were completely aware of this but their point of view was definitely not shared generally. As a result, the hand surgeon was often confronted with pedicle skin grafts which had been placed without regard to movements of the hand. On many, the borders of the pedicles were made to coincide with directions of push and pull and keloids and contractures resulted. Or the pedicle was insufficient in size to allow flexion of the joints concerned, or opposition of the thumb. Sometimes instead of a pedicle graft a split thickness graft was placed, making repair of the deeper structures impossible. Since open wounds even on a pedicle stiffen hands, the hand was often found to be unduly stiffened because an open pedicle graft had been placed instead of an aseptic one. Frequently, when a pedicle graft had been placed, data valuable in the future management of the patient were often missing, no note having been made of the condition of underlying muscles, tendons, and nerves, as if these matters did not concern the plastic surgeon.

Lesions of the nervous pathway, whether of the cerebrum, the brachial plexus or the nerves of the arm, are extremely crippling to the hand, often causing such deformity that the member is useless. But when a nerve in the forearm had been repaired on the neurosurgical service, there was complete neglect of repair of tendons or muscles in the same area. A second operation was therefore necessary. This had to be undertaken "blind," since the neurosurgeon frequently left no notation concerning the condition of the other structures. In some cases, the stretching of paralyzed muscles caused muscle imbalance. The neurosurgical service should work, therefore, in cooperation with the hand service, depending upon it for consultation concerning management of hand complications of nerve lesions. It is the duty of the hand surgeon in such cases to keep the hands in muscle balance and in the position of function and to keep the joints moving. Patients with such injuries should never be discharged from the neurosurgical service without being cleared through the hand service, since many casualties with irreparable nerve injuries can be rehabilitated by tendon transfer, arthrodesis, and other measures.

In World War II, hospitals with services for plastic, orthopedic, and neurosurgery always possessed great advantages in surgery of the extremities because of the interchange of ideas possible among surgeons in these fields. The weekly conferences [3] dealing with the problem cases in each field by the staffs of each specialty were always educational and conducive to better work, since they permitted the correlation of viewpoints and the rounding out of the whole subject. This was particularly true in hand surgery.

[3] See individual hand center reports.

## Personnel of the Hand Service

The assignment of personnel on the basis of interest in, and knowledge of hand surgery proved extremely difficult. Not many surgeons were qualified in the three fields necessary for the management of such injuries. Some of those best qualified were beyond reach; they were either overseas or in the Air Corps.

The desideratum was that the personnel of a special hand service should consist of a qualified operating surgeon, with an operating assistant and a ward surgeon. Such a team could easily care for 100 patients at a time and operate on from 50 to 60 hand injuries per month. The patients required an average of 2 operations each, but operations on hands took so long that a surgeon could not perform more than 2 or 3 each operating day.

The hand centers in the Zone of Interior in World War II did not in any instance attain the desired quota of surgeons. All were understaffed. By the fall of 1945, when hand centers were at their peak of activity, the surgeons assigned to them were operating on a total of 933 patients a month. At that time 4,542 patients were in the nine centers (Table 3) and it was estimated that it would take about a year to reconstruct their hands, allowing two operations per patient. The most serious injuries, moreover, required more than two operations. By April 1946 there were still many injuries to be cared for, as patients continued to enter the hand service from other services, especially the orthopedic and neurosurgical. It was then estimated that a residue of severe injuries could be expected through 1948.

## Qualifications for the Chief Surgeon of a Hand Service

Unusual qualifications were required for the chief surgeon of a hand service. He needed special interest in the work; he had to possess ingenuity. Not only did he have to have a good general surgery background but experience in plastic, orthopedic, and neurosurgery was required. To provide future teams he had to be able to teach the men working under him. All operating surgeons had to have the same kind of training and ability. Without these qualifications they were not able to operate independently on hands, nor could they safely do so. The skill and knowledge of a surgeon who operates on a hand determines whether he will wreck or reconstruct. Therefore, even assistant surgeons and ward surgeons needed to be selected on the basis of ability.

Many of the officers who carried on the work of hand surgery in the nine special centers in which these injuries were concentrated became extremely proficient in the reconstruction of hands and obtained excellent results by their strict adherence to fundamental principles. They had to be retained in service long after they might have been discharged on points because no others were trained to take their places.

## Courses of Instruction

In order to improve the quality of hand surgery in the Army, intensive courses, each lasting 3 to 4 days, were given by the Civilian Consultant in various general hospitals. Eight tours were made. The general hospitals, and the dates on which they were visited, were: [4]

29 November—
23 December 1944
Cushing
England
Valley Forge
Walter Reed
Baker
Wakeman

22 January—
23 February 1945
Beaumont
McCloskey
Northington
Lawson
Walter Reed
Percy Jones
Vaughan
O'Reilly

26 March—
25 April 1945
Torney
Bushnell
Barnes
Dibble
Hammond

27 May—
23 June 1945
Walter Reed
Cushing
Valley Forge
Baker

27 May—
23 June 1945—Continued
Crile
Wakeman

26 July—
26 August 1945
Birmingham
Beaumont
Brooke
Northington
Kennedy
O'Reilly

26 September—
20 October 1945
Dibble
Cushing
Valley Forge
Baker
Walter Reed

3 April—
30 April 1946
Dibble
Beaumont
O'Reilly
Wakeman
Baker
Crile
Cushing
Valley Forge

14 February 1947
McCornack

In all, 23 courses were given in 20 different hospitals and 49 additional visits made to 27 other general hospitals. These courses were attended by officers brought in from other hospitals in the particular service command.

In each installation instruction was much the same. It was assumed that the anatomy of the hand was known and little emphasis was placed on this phase. Six lectures, each an hour long, were devoted to the hand in its entirety. These were supplemented by lantern slides and moving pictures. Subjects discussed included the normal hand, methods of examination, principles of recon-

[4] Reports to The Surgeon General from the Civilian Consultant for Hand Surgery to the Secretary of War. HD: 730.

struction, methods of skin coverage with special attention to types of pedicles; injuries of the joints with special attention to the position of function and to mobilization; injuries of the bones, tendons, and nerves. Several conferences were then held and 50 or 60 patients examined in the course of each session. After each patient had been observed, suggestions for treatment were made by the Civilian Consultant. Suggestions were solicited from others present and new viewpoints invited, especially from the plastic, orthopedic, and neurosurgeons in attendance.

Operative demonstrations were part of the course. The Civilian Consultant sometimes performed the operations himself and sometimes assisted the surgeons on the service.

## REPORT ON HAND DEFECTS AND RECOMMENDATIONS FOR IMPROVED CARE

On the basis of the Civilian Consultant's observations on the management and care of hand injuries in general hospitals he called attention of The Surgeon General [5] to too many cases showing:

1. Malunion of phalanges, especially metacarpals, showing zigzag positions of fragments and overlapping due to lack of proper degree of early traction. There were also rotation deformities and shortening.

2. Proximal finger joints stiff and straight (Figs. 1 and 2). When fixed in this position joints cannot be flexed due to shortening of their collateral ligaments. This is usually preventable by early traction in flexion and early exercise in flexion.

3. All joints stiffened from splinting too much of the hand, not keeping the digits moving, and splinting for too long a time. Many deformities were the result of straight board or banjo splinting, with fingers and palm straight instead of in the position of function.

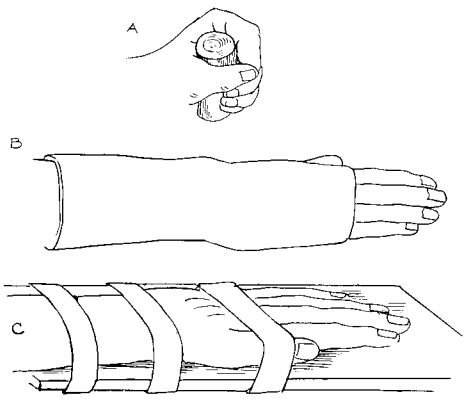
4. Wrists in plaster of paris in the straight position instead of dorsiflexed.

5. *a.* Hands not put up in the position of function. When at rest the hand assumes a certain position, largely the midposition of the range of motion of each and every joint, including the wrist and rotation of the forearm. The muscles are balanced; the forearm is halfway between pronation and supination; the wrist is in about 20 degrees of dorsiflexion and 10 degrees of ulnar flexion; the fingers are slightly flexed in each of their joints, the index being flexed least and the little finger most. The thumb is forward from the hand in partial opposition and its joints are partially flexed. The cleft between the thumb and hand is directly in the line of the forearm for reaching forward for grasping.[6]

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[5] See footnote 4, p. 23.

[6] *Position of function* referred to throughout this volume is defined precisely above.



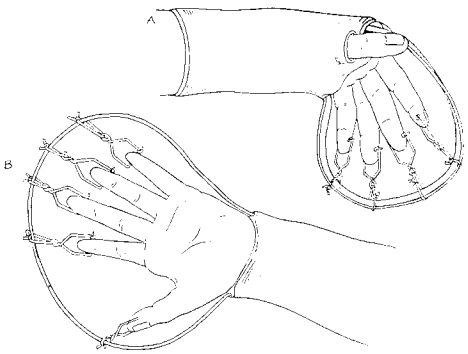




*Figure 1.* (*Left*) *Three incorrect ways of splinting hand, all of which contribute to crippling. A. Bandaging all fingers over a roller bandage stiffens the hand as a whole and the joints of all fingers. Only the injured digit should be splinted. The others should be left free to move and should be kept moving. B. A plaster cast should not be applied with the wrist and fingers straight and should never include uninjured fingers beyond the distal crease of the palm. The results of incorrect splinting of this type are that the proximal finger joints will be stiff and straight and the whole hand and forearm unexercised. Wrist, arches, thumb, and fingers should be in the position of function. C. Strapping a hand to a board stiffens the whole member in a position of nonfunction, wrist straight instead of dorsiflexed, palm flat with loss of metacarpal arch, thumb at side of hand instead of in opposition, and finger joints straight.*

*Figure 2.* (*Right*) *The banjo-type splint which wrecks many hands. It pulls the fingers in a straight or wrong position, throwing fractures out of line and stiffening all joints of all digits. Fingers in traction should rest semiflexed on an extension support, as in Figures 14 and 15. A. Fingers in semiflexion should converge* (*as in Fig. 15D*). *The thumb should not be enclosed in the cast; the wrist should be in dorsiflexion. B. The fingers are pulled in the straight or wrong position and are not really splinted, as the hand flaps back and forth. This type of splinting will result in much stiffening and in malunion.*

The position of nonfunction is the opposite. The wrist is flexed, the fingers cocked back, the thumb is drawn to the side, and the metacarpel arch is flat or reversed and the carpal flat. All injured hands tend to go into that position, whether from paralysis, injury, or infection.

*b*. Hands with muscle imbalance resulting from nerve injury were unsplinted.

6. Hands greatly indurated, with large scars and flexion contractures from not having been closed over early by skin grafts. Wounds had been allowed to remain open too long. Granulation tissue piled up and eventually contracted into cicatrix. This could have been prevented by early closure by skin graft.

At the same time he made the following suggestions:

1. Splints with which joints can be drawn into the position of function should be made in local brace shops (Figs. 3–13). With plaster of paris, cas-

tex, or metal a splint can be made to correct the deformity of median and ulnar palsy. For radial nerve palsy the light Oppenheimer wire splint is desirable. It is cheap and easy to make, fits through a coat sleeve, checks only the joints desired, and allows free movement of muscles, tendons, and joints in the forearm and hand (Fig. 11). (Later the Thomas splint proved more efficacious (Fig. 12).) For small miscellaneous splints for digits, strips of inexpensive vinylite sheets held over a Bunsen burner can be fashioned quickly as desired.



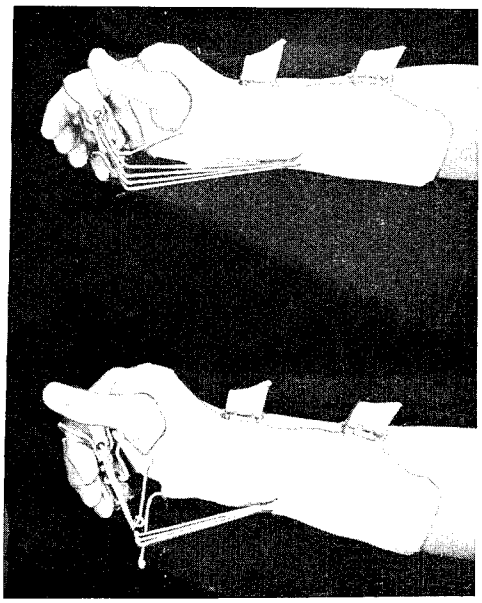


*Figure 3.* (*Left*) *Cock-up splints of flat spring steel or piano wire designed to dorsiflex wrist and furnish exercise. Upper view shows wrist in dorsiflexion and lower view, in flexion.*

*Figure 4.* (*Right*) *Splint designed to flex and exercise proximal joints of fingers. Direction of pull of rubbers is adjusted by bending outrigger.*

2. Joints and stiff hands loosen up better under actual use than under passive therapy. Benefit from the latter is transient, but it may be used for the first week or two. Heat is beneficial for the short time each day that it is applied, but rough manipulation of finger joints is harmful, and lights and electricity are of very doubtful value. Occupational therapy gives good results, and its use should be encouraged. Wood blocks with holes (Fig. 16) which place fingers in desired positions can be used for sandpapering and furnish excellent exercise. Also useful are the various occupational procedures which place a man in work which will be beneficial for his hand.

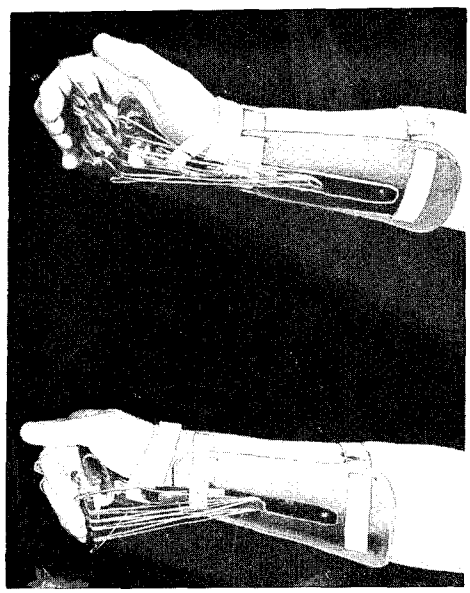


*Figure 5. Metal spring splint with outrigger, over which has been slipped metal tubing to act as a roller, bent to give the desired direction of pull of the rubbers. Upper view shows dorsiflexion of wrist and extension of proximal joints of fingers. Lower view shows flexion of wrist and of proximal finger joints.*

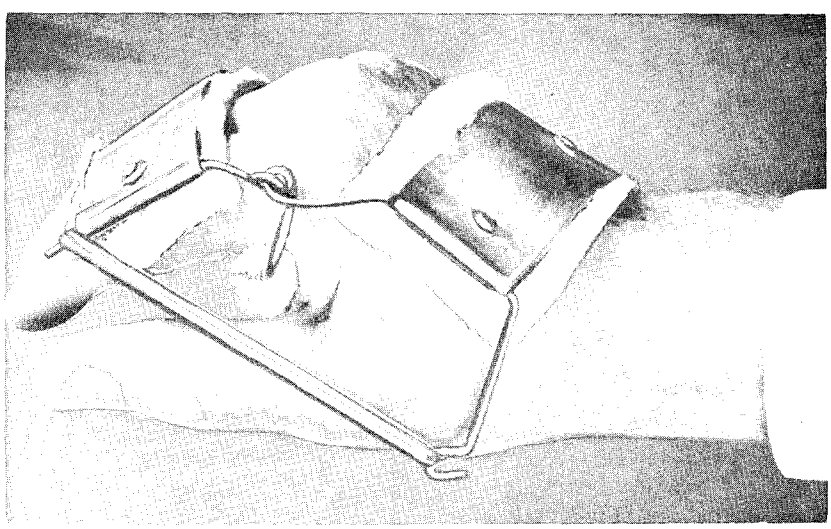


*Figure 6. Knuckle bender splint designed to flex and exercise proximal joints of fingers. The splint has three padded points of pressure activated by rubber bands, with pivots corresponding to the axes of the joints. Motion is carried through the full range. Rubber over the thumb helps to oppose it.*

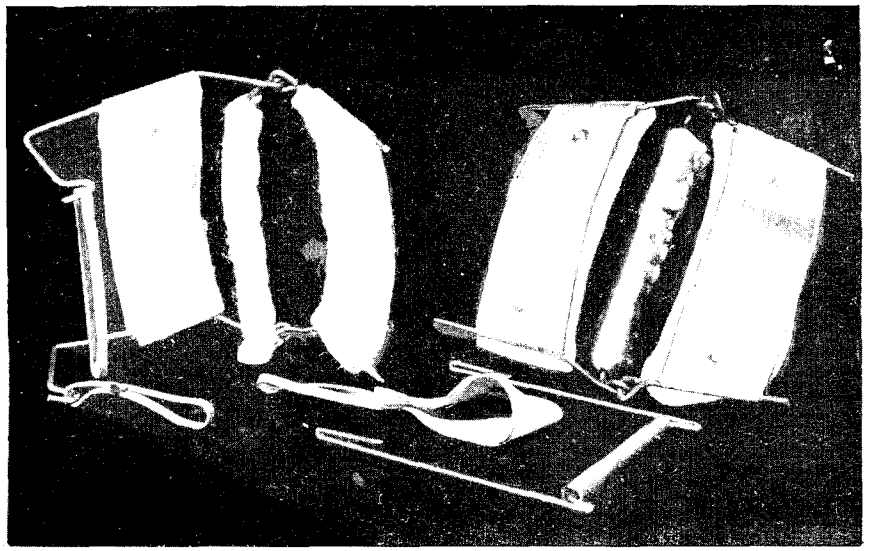


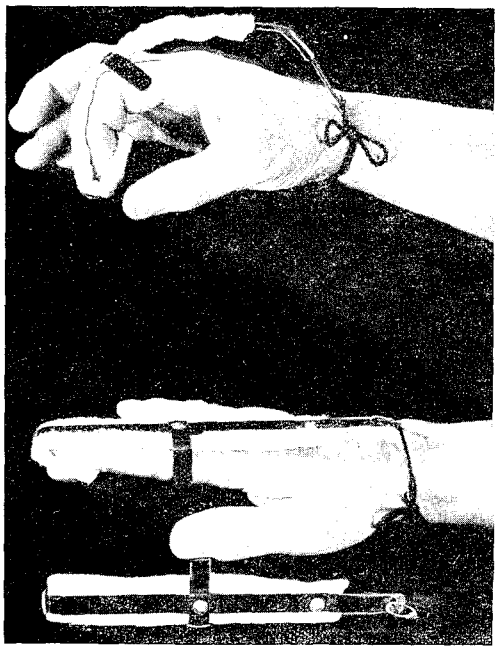
*Figure 7. Detail of knuckle bender splint with leather loop and rubber designed to draw the thumb into opposition. Note the outrigger with tube roller, over which leather loops and rubber bands draw the fingers into extension in the correction of claw hand.*

## CLINICAL POLICIES IN MANAGEMENT OF HAND INJURIES

The major part of hand reconstruction was accomplished in the nine general hospitals in the Zone of Interior designated for the specialized treatment of hand injuries. Minor hand injuries were treated in the hospitals to which the patients had been assigned, while those with injuries other than of the hand were sent to other specialized centers for the treatment of those injuries.

Conceding that all knowledge was pooled and every hand surgeon had full access to existing information, this could not alter the fact that each individual thinks and approaches problems differently and has a different type of ingenuity. These variations are of particular importance in hand surgery, in which each case constitutes an individual problem. For this reason, although a certain amount of repetition is inevitable, the reports of the nine hand centers are published separately. The stories told by individual surgeons who treated hand injuries in the Zone of Interior provide a fuller and more rounded concept than a composite report could accomplish.

In the sections which follow are set forth the principles and policies taught by the Consultant in Hand Surgery on his visits to the hand centers and various other hospitals in the Zone of Interior during World War II. They form the basic clinical principles upon which the management of hand injuries was predicated.



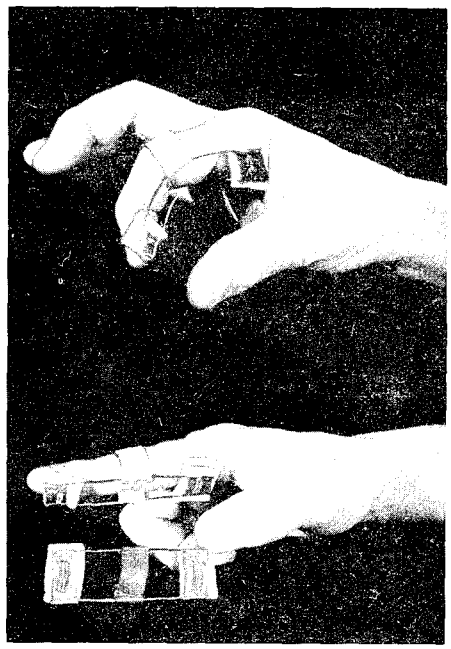


*Figure 8. (Left) Simple splint of clock-spring designed to draw fingers into extension. The range of motion is demonstrated: (upper) flexion; (lower) extension.*

*Figure 9. (Right) Safety pin splint of spring wire (0.033 inch) designed to straighten finger. The two views show the spring motion.*

## Importance of the Hand

A man with a crippled hand is unfit to be a soldier. He cannot serve with combat troops, nor can he do manual work. The hand is the important part of the arm, and from a functional viewpoint it may be considered a manual unit which begins at the elbow, since the muscles of the digits have their origin high in the forearm.

Organically and functionally the innervation of each hand starts at the opposite cerebral cortex and a lesion of the nerve pathways anywhere from the cortex to the hand itself cripples the hand just as surely as does an injury to its structures.

The action of the hand depends upon the condition of the bones and the movements of the joints of the forearm as well as upon the condition of the nerves of the forearm. The purpose and use of the arm are to activate the hand and to place it where it can work. An arm without a hand, even when a prosthesis is supplied, is not of much value.

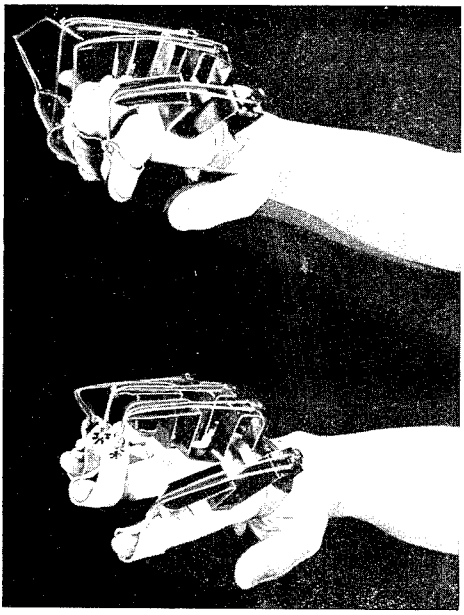


*Figure 10. (Left) Splint of clock-spring and rubber bands designed to extend distal two finger joints and exercise the fingers. This splint was developed at Dibble General Hospital by Sgt. S. L. Cravath and Lt. Col. Donald R. Pratt.*

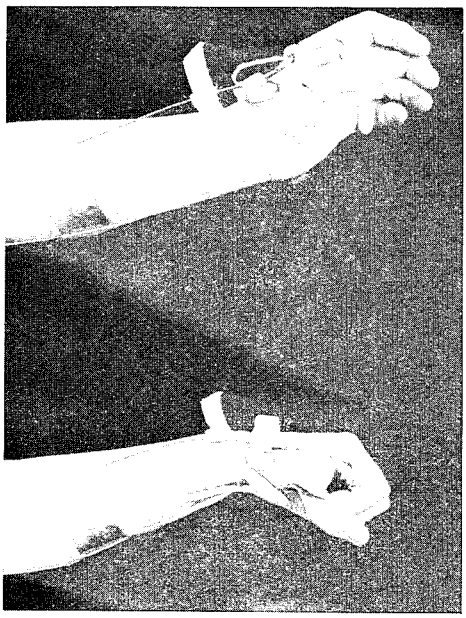


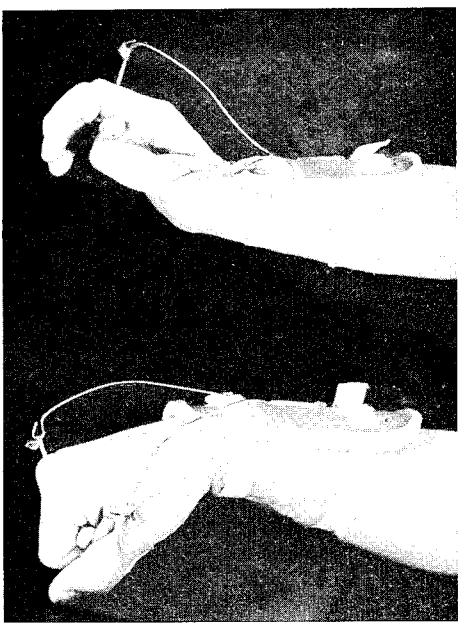
*Figure 11. (Right) Modified Oppenheimer splint used to balance the muscles in cases of radial palsy. The main spring wires are light (0.069 inch). To give free mobility the thumb is held by a leather loop and light spring wire (0.033 inch) instead of a rigid ring. Strap passes through wire rings to retain splint in place. Upper and lower views show motion possible.*

## Initial Treatment

Most hands injured by gunshot wounds which were seen in the hospitals in the Zone of Interior by the Civilian Consultant presented considerable crippling which could have been prevented by proper selection of initial treatment in the theaters of operations and in communications zones. To guard against continuation of these deformities, the following suggestions for the improvement of early treatment were advanced:

When the hand is first wounded the patient should have sterile dressings and a bandage applied to the wound; he should then be sent back through the battalion, collecting, and clearing stations.

Initial repair should be done in a hospital with good operative technique. In preparation for operation at the evacuation hospital where the first definitive work is done, good operative facilities are required. These include a pneumatic tourniquet, anesthesia, good asepsis, masks, gloves, gowns, and protection of the



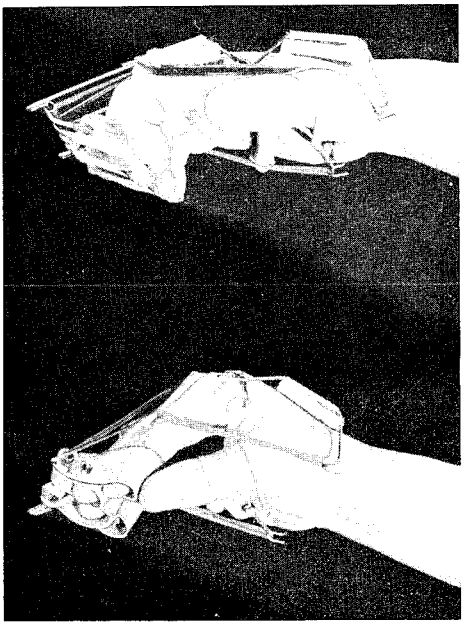


*Figure 12.* (*Left*) *Modification of spring wire suspension splint* (*Thomas*) *for radial palsy, designed to furnish muscle balance and complete freedom of action for manual work. The spring wire which holds the thumb is very light* (*0.045 inch*) (*0.075 for wrist*). *The degree of possible motion is demonstrated.*

*Figure 13.* (*Right*) *Elastic knuckle bender splint used in combined median and ulnar palsy to restore muscle balance by substitution for paralyzed intrinsic muscles. Upper view shows position of claw hand with thumb at the side and proximal finger joints straight. In lower view, position has been corrected by elastic pull of rubber bands which straighten clawed fingers, flex proximal joints of the fingers, draw the thumb into opposition, and curve the metacarpal arch. Detachable wire outrigger with metal tubing roller has been snapped into place.*

wound against contamination. Penicillin should be started. The limb should be shaved, scrubbed with soap and water, and wound ischemically with an ace bandage. The wound itself should be thoroughly cleansed with lots of normal salt solution. An Esmarch tourniquet should not be used because the many turns add pressure and numerous cases of paralysis have resulted. Several layers of sterile cloth are placed between the arm board and the top sheet so the fluid will not carry the germs through. Sterile sheets are then placed, clamping the one under the arm about the upper arm below the tourniquet.

Adequate anesthesia should be used. Block anesthesia might be employed upon occasion but thiopental sodium permits the surgeon to work freely from one part of the body to another.

The wound is then debrided. A thin layer of the damaged surface should be excised and foreign bodies removed, avoiding cutting the nerves, vessels, joint capsules, or tendons. Severed nerve ends in the forearm may be joined by a single stitch of stainless steel wire to prevent retraction. Joint capsules should be closed to wall out infection. Through-and-through drains should not be used. Gauze should then be placed loosely between the fingers, and the hand put up in the position of function, encompassed in a voluminous dressing of gauze fluff, then wound with an elastic cloth bandage with sufficient pressure to prevent edema. A volar plaster splint is applied outside the dressing. The hand should be kept elevated. Penicillin by the parenteral route is continued

## Early Reparative Treatment

When the patient arrives at a general hospital, usually within 4 days to a week after injury, reparative treatment is begun. Fractures should be set, digits placed in the position of function and so they will be opposable, and the wound closed by simple suture or by other methods, chiefly skin grafting. If closure cannot be accomplished by simple suture a thick skin graft can be used; it can later be replaced by a pedicle graft. Fractures should be set early, under mild traction (Figs. 14 and 15) and the hand splinted in the position of function. Distraction causes nonunion, adhesive traction is usually sufficient. At this stage the entire skeletal alinement should be corrected and a concentrated, continuous effort devoted to keeping the hand mobile henceforth.

Traction is so often applied incorrectly (Fig. 2), both in the placing of the wire and in the application of pull at a wrong angle, and so much damage has resulted, that all surgeons should study carefully the use of this method. If the positions of fractured metacarpals and phalanges are corrected at this stage, much crippling can be prevented. Attention to the position of fractures saves the later necessity of correcting deformities by osteotomy. If traction is applied with the proximal finger joint in flexion (Fig. 15 B), collateral ligaments will remain elongated and later the joint will be able to move. If these ligaments are allowed to shorten, the proximal joint will become stiff and straight. Correct rotation of the bone may be ascertained by observing the plane of the fingernails and the plane of the motion of flexion of each of the fingers (Fig. 15 D). Planes of motion should converge to the tubercle of the scaphoid.

All undamaged parts should move (Fig. 74). Long-continued splinting stiffens hands and is not necessary, since most metacarpal fractures unite within a month. Maintaining the position of function, together with persistence in active motion of all the uninjured digits, will save months of disability. Special care should be used to keep the proximal finger joints in flexion and prevent stiffening.

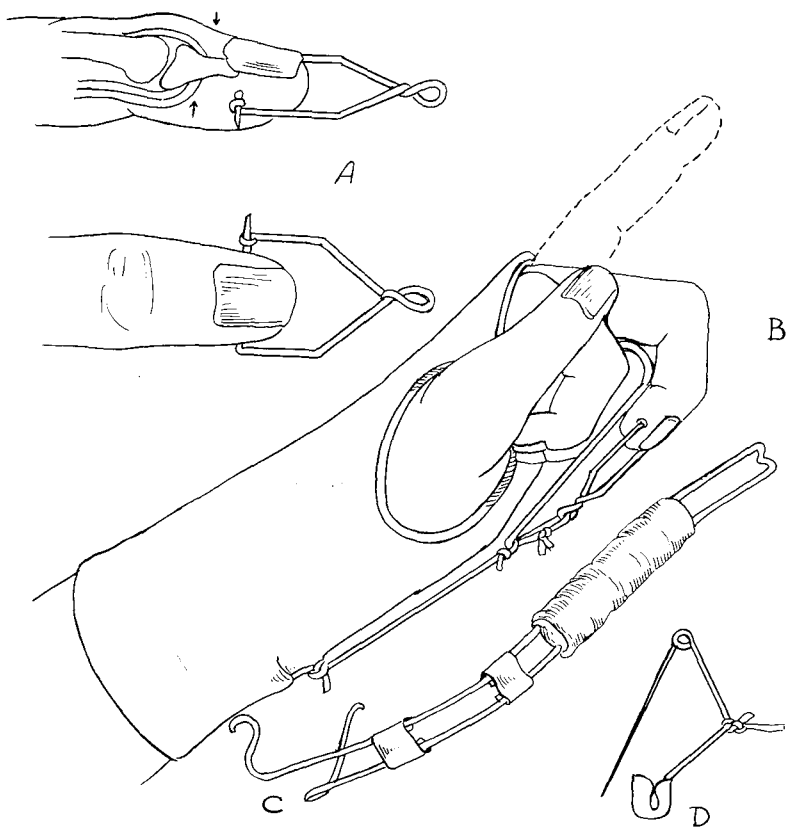



*Figure 14. Correct application of pulp traction for fracture of phalanx or metacarpal. A. Pin transfixes finger at correct site, avoiding matrix (upper arrow), nail, phalanx, and tendon sheath (lower arrow). B. Plaster cast embraces hand and forearm. It stops at distal crease in palm, leaving the uninjured fingers free to exercise throughout their range of motion, and at thenar crease, giving thumb free motion of opposition. The finger in which the phalanx or metacarpal is injured rests on a padded wire extension (C) which is incorporated into plaster. A cord from wire to cast at the forearm maintains the flexion. C. Extension made of soft iron wire with two strips of tin and padding. (A strip of duralumin may be used instead.) D. Method of using a steel safety pin for pulp traction. The point is cut off after transfixion.*

Casts should not be too tight, and uncut circular casts should not be used. Effects of constriction from swelling in tight casts consist of all grades of Volkmann's ischemic contracture and with it, or independent of it, contracture of intrinsic muscles of the hand. For the latter deformity, the position of function and use can be improved by tenotomy, or if muscle function has been destroyed, by excision of the contracted muscles, or stripping the muscles and

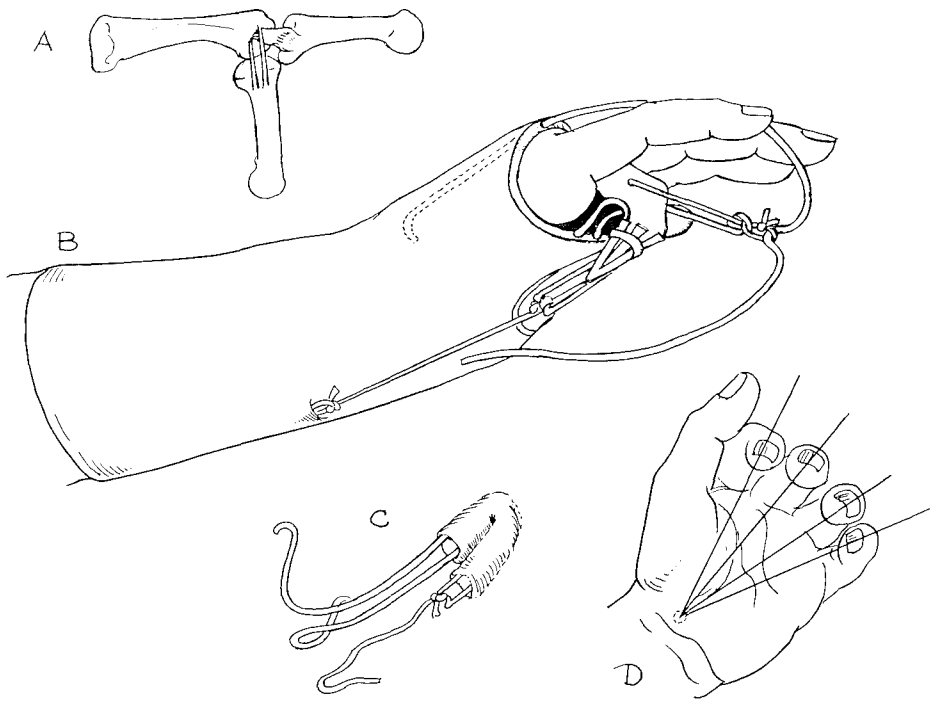



*Figure 15. A. Collateral ligaments of proximal finger joint tight in flexion but relaxed in extension. If the joint is splinted in flexion and with skeletal traction it remains limber. B. Correct application of skeletal traction for fracture of metacarpal. Wrist in 20 degrees dorsiflexion, proximal finger joint in 45 degrees flexion. Thin Kirschner wire transfixes the neck of the proximal phalanx and is bent, as shown for traction, to stiff wire extension loop from plaster cast. The finger is steadied by adhesive plaster on a wire extension (C) to maintain correct rotation. D. Guides to correct rotation in setting fractures. In partial flexion the planes of the fingernails form an arch and the planes of motion of the fingers converge to the tubercle of the scaphoid.*

advancing them distalward if they are still active. Correct early treatment would make all of these operations unnecessary.

## NERVE INJURIES

As already pointed out, the hand is controlled from the functional dynamic standpoint by the nerves from the opposite cerebral cortex, through the brachial plexus, and the nerves of the arm. An injury to the nerves of this pathway may, therefore, cripple the hand quite as much as, or even more than one of the hand itself. The loss of sensation and motion results in deformity and stiffness and renders the hand quite useless.

When a nerve is severed, its distal portion and the muscles supplied by it undergo progressive fibrous degeneration which is irreversible and renders recovery impossible unless checked early by nerve regeneration. Repair of the nerves of the arm should, therefore, have priority over repair of the other structures.

Nerves regenerate sooner and better when repaired at once after the injury providing the best technique is used and the wound is not explosive or dirty but of the type that heals primarily. The nerve ends should be trimmed back only a little in knife-cut wounds but further back in wounds of greater trauma. If not suitable for primary suture, the two nerve ends should be fastened together with one stainless steel suture to prevent retraction.

When not sutured primarily, they should be joined as soon as the wound is healed and danger of latent infection over. Each day of postponement results in more fibrous degeneration of nerve and muscle. Severance of a nerve, therefore, constitutes an emergency demanding prompt repair. After a lapse of 2 years before nerve suture, motor return to any practical degree cannot be expected. However, sensory perception may return even after a 5-year lapse.

Early nerve repair provides the additional advantage that joints may then be flexed. It is impossible to bring nerve ends together if the joints have stiffened in extension. To approximate nerve ends when the joints will not flex, it may even be necessary to bend the arm at the fracture site or to separate a fused joint. Repair of bones and joints can be carried out later as they are of less importance. The median and ulnar nerves are most important for preservation of the hand. The loss of the radial nerve can be somewhat compensated for by tendon transfers. By consultation between surgeons in charge of neurosurgical, orthopedic, and hand services the point of view of priority of nerve repair can be arrived at with the resulting salvage of many hands. Too often in World War II, nerve suture was postponed until the repair of bones or joints had been accomplished. At the end of 2 or 3 years these patients presented pitiful, uncorrectable deformities of the hands. These were the patients with hand injuries still in the hospitals in the Zone of Interior in 1948. This is the more deplorable considering that the hand is the important part of the upper extremity and does the work, the arm merely placing and enervating the hand.

*Repairing Nerves.* Officers should early be alert to discover nerve damage and not be too conservative in delaying treatment. Though nerve function lowered by attrition may at times recover, when in doubt it is better to explore early. The nerve may be inspected without injuring a limb, thus giving the patient a chance for neurolysis or neurorrhapy. If primary suture were done with not the best surgical facilities, the juncture should be resutured meticulously as there will generally be found a rough union which would result in only partial recovery.

Instead of dissecting out a nerve at site of injury, it should be uncovered in good tissue above and below the injury, continuing the dissection along the

nerve to the injury. Before raising it from its bed, markers of silk suture are placed on the uppermost part of each nerve above and below the lesion as a guide to exact rotation lest motor fibers grow down sensory pathways and vice versa.

The ends are trimmed off squarely until good scar-free axone bundles present, and are accurately joined by No. 7–0 silk sutures through the sheath only, matching up correctly distinctive axone bundles and any markings or shape seen in the nerve ends; then after placing guide sutures the sheath is so accurately sutured that no axones will escape to be lost and give Tinel's sign.

A proper bed of good tissue should be prepared and the nerve laid in it. Usually a flap of nearby fat or fascia may be turned over or the nerve rerouted to be between muscles or good tissue. If placed through a muscle or back in scar tissue, cicatrix will penetrate into and strangle the nerve, jeopardizing the result. Intubation by blood vessels or foreign membrane is nonsurgical. It inhibits blood supply and causes irritative cicatrix. Tantalum foil is especially pernicious in this respect.

Gaps between nerve ends, even up to 5 inches, may be overcome by the following methods: Each nerve end may be freed from the surrounding tissues to past the joint below and the joint above. On flexing one or both joints, the nerve ends approximate. If flexing the wrist and elbow is insufficient, the nerve may be freed higher through other incisions and the arm flexed and adducted at the shoulder. If the lesion is in the brachial plexus the scalenus anticus may be severed and the clavicle resected, the neck flexed to the side, and the arm adducted across the chest. The position is maintained by a plaster headcap, an axillary sling, and the hand fastened to the opposite shoulder. Further length is gained by transposition. The ulnar, median, and radial nerves may be rerouted well forward, splitting up their branches to avoid tension, and be made to span widely the flexed elbow. The outer head of the pronator teres is severed to free the median nerve. At the wrist, 2 inches can be gained in the median nerve by acutely flexing the elbow and then sliding the nerve down the forearm. This must be done understandingly. The branches will not be broken and the nerve not overstretched. Stretching a nerve does damage.

Flexion of the joints is maintained for a full month before subjecting the junction to strain. Three weeks is not sufficient. Twice a week the joints are then let out very gradually by the snub method, that is, a splint is made to snub extension but the limb is free to flex voluntarily, thus relieving any ischemia in the nerve which would make itself known to the patient by discomfort. The nerve is not stretched longer but is made to grow longer from 2 weeks to 1 or 2 months, depending on the length of the gap overcome. Unless the elbow can flex, gaps in arm nerves cannot be corrected. A conspicuous note should be placed on the chart, stating the amount of joint flexion that must be maintained and the caution to use in extending the joints.

A gap may be overcome in two stages by bulb suture. First the neuroma and glioma are fastened together by a stainless steel wire stitch and the joint flexed as above. Then after gradually extending them the procedure is repeated, suturing the nerve.

*Nerve Grafts.* Nerve grafts were used successfully providing the grafted nerve was small enough in diameter to be nourished through and through. Thus, cable grafts up to 4 strands of sural nerve and as long as 6 inches were used.

Nerves severed within the hand should and can be repaired even to as far distal as the distal flexion crease in a digit. They are sutured just as are large nerves with from 2 to 4 No. 7–0 silk Weldon corneal eye needles. To overcome a gap in the palm, the main nerve is drawn down the forearm as described above or a nerve graft is used. The motor branch of the median or ulnar nerves may need slitting up from the main nerve to allow this. Even these two motor nerves are not too tiny to be sutured successfully.

Sensation is equal to motion in value of the hand and in contrast to motor function can generally be restored by nerve suture, even up to 5 years. The prognosis after nerve suture depends largely on the state of nutrition of the hand and on how the surgery and after treatment were carried out. If function of the intrinsic and other muscles does not return, it can be substituted for by tendon transfers.

## PLASTIC SURGERY ON THE HAND [7]

Certain features peculiar to the hand call for special lines of thought and procedure in planning its plastic repair: *The source of its nutrition is longitudinal, through the narrow wrist; the hand is a mobile organ, not to be restricted by lines of scar; it is a tactile organ; it is a prehensile organ; it contains many important deep structures; it is prone to stiffen.*

### Excision and Pedicle Replacement of Cicatrix

A cicatrix is an avascular fibrous infiltrative process that contracts and binds all structures, both deep and superficial. Movable structures are bound, and lifelines such as blood vessels, lymph vessels, and nerves are strangled. A cicatrix impoverishes the hand. It may infiltrate the whole hand or may lie along its only source of supply, the forearm or the narrow wrist. Even if a cicatrix is on one side of a limb only, it acts as a veritable girdle, both deeply and about the surface, and even the two-thirds of the circumference that is unaffected will be tight.

[7] Only the important principles of plastic surgery of the hand are contained in the following material. Illustrations of the various techniques described, with case records, appear in the reports of the various hand surgery centers.

As in repair of deep structures anywhere else in the body, the cicatrix should first be excised and replaced by good pedicle skin. If operation is done through a cicatrix, wounds will not heal, structures will not be movable, bones will not have sufficient blood supply to unite, and the nutrition of the hand will not be improved. Repair should start with the excision of the cicatrix, the skin borders of which should be undermined from the deep fascia and allowed to retract. The defect is then filled with good pedicle skin. At the next operation for repair of the deep structures, the deep cicatrix is dissected out and excised en bloc, freeing the deep structures. The liberating effect of this procedure permits the hand to breathe and thrive again. Nutrition is restored and every structure improved. This concept goes far beyond the mere removal and replacement by pedicle of a surface cicatrix, with no regard for excision of the deep cicatrix from between the deep structures or for thorough freeing of the skin borders.

If flexion contracture is present, and if on stretching the skin whitens, the skin is obviously the primary cause of the contracture, the deep structures being secondarily contracted. If the skin does not whiten, the reverse is true: deep tissue contracture is primary and skin contracture secondary.

*Determining the Size of the Skin Defect.* The size of the skin defect is ascertained by comparative measurements on the fellow hand with all its joints placed in the position opposite to that caused by the contracture. Comparative distances between various similar pairs of points are taken: longitudinally down the wrist, palm or fingers; transversely in various lines across the palm, with all digits fully spread, and along the dorsum with all fingers fully flexed. In estimating the size of the pedicle, one-third more than the actual measurement is added to allow for the tightness of the skin about the contracture. Before a hand can be placed in position opposite to that resulting from the deformity, the deep portion of the flexion contracture, whether fascia, tendon, or joint capsule, must be released.

## The Hand as a Mobile Organ

The skin of the hand is so specialized that it covers the hand throughout without strain, irrespective of the many positions this versatile and mobile organ may assume. Surgeons too frequently, unmindful of this phenomenon, apply skin to the hand merely as a surface patch to replace a cicatrix. If the borders of such a patch coincide with the directions of push and pull, they are subject to the irritation of these movements and will form thick, contracting, keloid-like scars.

*Incisions.* Therefore before any incision is made in the hand, certain principles must be considered: *Incisions should parallel the wrinkles or flexion creases wherever possible and never cross them at or near a right angle; median longitudinal incision anywhere in the hand is pernicious.*

On the dorsum of the hands fine cross-wrinkling provides for longitudinal stretching of skin from forearm to fingernails when a fist is made with the wrist in flexion. There is also transverse stretching of the dorsal skin under the same circumstances. Special redundancy of the skin over the knuckles permits free movement in that region. In fact, the total area of dorsal skin of the hand and fingers is one-third greater when a fist is made. Plastic surgeons must bear these features in mind.

An example of error is a pedicle graft placed as a circular patch on the dorsum of the hand so that the distal border parallels the thumb web and the proximal border forms a line across the back of the hand. As a result of the motion of push and pull, the border along the web thickens to a keloid contracture, and the proximal border contracts so that the thumb cannot oppose and the metacarpal arch cannot curve.

The volar aspect of the hand is cleft by deep folds which take up the slack of the skin when a fist is made. The total volar skin area when a fist is made and the wrist is flexed is very small compared with the area when the hand is spread and the wrist is dorsiflexed. The folds are transverse in the fingers, thumb, palm, and wrist. In the palm they are also oblique, to accommodate closing and spreading between the thumb and the last three fingers. If a surgeon bears in mind the importance of these phenomena, he will not place an incision or a border of a pedicle or free skin graft directly across either the deep volar folds or the fine dorsal wrinkling. He must picture the hand as mobile and arrange the scars to accommodate motion in any direction.

When new skin is supplied to the hand the amount should be ample to cover it when hand and wrist are in complete flexion as well as in complete extension and dorsiflexion. Enough skin should be allowed to include any additional slack needed for full pronation and supination. Transversely, the palm should have sufficient skin to accommodate for the full spread; similarly, the dorsum should have enough for opposition of the thumb and for a fully curved metacarpal arch.

A zigzag or curved line should be made whenever a scar or the border of either a pedicle or a free graft must cross a flexion crease at a right angle, that is, must coincide with the direction of push and pull. A cross slit may be cut and a tongue of skin drawn into it, or the patch may be patterned with indentations and blunt points. A long tongue of graft should be laid across the web to eliminate a scar which would parallel it.

The pedicle graft intended to fill a thumb cleft should be long and diamond-shaped, with the points or angles reaching to the juncture, or hinge, of the first two metacarpals anteriorly and posteriorly. A scar made along the midlateral line (at which the flexion creases terminate) will become almost invisible, but a scar placed volar or dorsal to it will thicken and contract because it will be subject to the irritation of push and pull. Free grafts intended to replace scars from burns along the dorsum of the finger should be constructed with zigzag

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borders or with enough skin to allow the borders to follow the midlateral line of the finger on each side. Since the wrist is a universal joint, longitudinal scars or graft borders in any part of its circumference are undesirable.

In an endeavor to furnish ample skin, pedicle grafts are often made excessively thick, so that they stand out in a grotesque dome. Except in a few special cases such as clumped fingers this is a fallacy, because skin itself will grow to cover any area at normal tension. It is the borders, not the skin itself, that are unyielding and that contract instead of elongating, and hamper motions. Too much fat is parasitic and is an additional burden on the blood supply. Pedicle skin should be trimmed fairly thin, leaving just enough fat to provide a layer between the tendons if it is needed. As seen on cross section, the main blood supply is between the fat and the skin and it is therefore safe to trim away excess fat. The deep feeder vessels that supply the plexus in the skin may be left in the thick stem of the pedicle. To correct excessive fat in a pedicle requires two operations.

The skin is only a part of the problem. To facilitate identification of the deep structures such as nerves, tendons, blood vessels, pulleys, and joint capsules, and to spare them injury, all dissections of the hand should be done under the ischemia of a pneumatic tourniquet. Severance of the motor thenar nerve destroys opposition, and severance of a volar digital nerve destroys sensation. Incisions that parallel tendons cause adhesions to the tendons for their full length. Skin replacements should be planned so that when later the deep structures are repaired, a flap may be turned back and the scar need not be placed over the repair.

## The Hand as a Tactile Organ

In the hand sensation is equal in value to motion. The hand is a sense organ specialized for stereognosis, particularly in the area supplied by the median nerve. The pulps of the thumb and the first three fingers are the eyes of the hand. They are rich in special touch corpuscles, the most sensitive spot in each being the whorl of the fingerprint, where rugae furnish separate points of contact for crisper images.

When a new thumb or finger is constructed using pedicle skin taken from the abdomen, or when a patch of skin is placed on the tactile surface of a digit, enough sensation to distinguish touch and pain will eventually appear, but it will not be at all the same quality that makes for stereognosis in the finger with normal skin. *In these delicate touch areas, it is well, whenever possible, to transfer normal skin from the vicinity for pedicle skin to furnish the quality of sensation, and, whenever possible, also, to provide for the nerve attachments to accompany the skin flap.* When a finger is to be discarded its volar skin may be utilized by transferring it as a pedicle, with blood vessels and nerves intact, to the digit which is in need of tactile covering. In reconstructing a thumb, it

is greatly advantageous to perform the operation by transferring another digit with its blood vessels and nerves attached to the site of the old thumb, so that the new digit will have normal sensation.

## The Hand as a Prehensile Organ

An important function of the hand is the ability to oppose one digit to the other, in order to pick up or hold objects. This ability can be furnished in an injured hand in several ways. If all digits have been amputated, the metacarpals may be phalangized for depth of clefts, and the second and fourth excised for width of clefts. After loss of some digits, the remaining ones may be made to oppose each other by angulatory rotary osteotomy through the bases of their metacarpals. Additional strength should be given these digits by transferring to their tendons the tendons of the unused muscles in the forearm.

If a thumb is lost, a new one may be furnished by transferring the index finger, or what is left of it, into its place so that the new digit has the advantage of sensation and motion. A thumb may also be reconstructed by tube pedicle and bone graft. If part of the metacarpal is present, the thumb will have motion. If the thumb is to be an immobile post, it should be short and thick. A new thumb should be made in the path of movement of the fingers, and so that fingers can pass it. A thumb placed out of this zone of movement is useless. If a new thumb is without sensation because it was made by pedicle graft, it should be kept protected by a thumb stall before being used, until it acquires sensation to pin prick. Otherwise, a trophic ulcer may form and destroy the bone graft.

## Stiffening of Hands

*Open Wounds Stiffen Hands.* As previously mentioned, too much and too prolonged splinting stiffens the hand especially if it is already swollen when the splint is applied. The products of inflammation, even in the course of a few weeks, result in considerable stiffening. Wounds in hands should therefore be closed early, by primary or secondary closure or skin grafting. The application of pedicle skin will solve the problem. The open pedicle method (that is, the septic pedicle) should never be used on the hand. The open stem of a pedicle is equivalent to an open wound. The lymphatic vessels carry the products of inflammation directly into the hand and will bring about very undesirable stiffenings. All pedicles to hand should be rendered aseptic by closure, either by tubing or skin grafting over all raw surfaces. Neat, careful suturing of pedicles produces clean healing instead of dirty borders. In the prevention of stiffening after plastic surgery it is important to avoid collections of serum or blood by practicing careful hemostasis, placing drains for 24 hours, and avoiding dead space and edema by building about the pedicle a firm pressure dressing that fills in every interstice.

## New Covering

In supplying pedicle skin to injured hands in many thousands of cases in Army hospitals in World War II, the direct abdominal flap in a single stage, which is timesaving, proved the method of choice except when a tube pedicle was indicated. The latter is better adapted to use on bizarre-shaped areas, especially those involving the fingers. It is also useful when the hand cannot reach the donor area because of loss of pronation and supination. Direct flaps, with a broad flaring base and a maximum length to breadth proportion of $2\frac{1}{2}:1$, are made in a vertical direction along the network of the thoracoepigastric vessels and are turned up or down as desired. The arm is strapped to the abdomen and moves with the abdominal skin. The under surfaces of the pedicles are rendered aseptic by skin grafting and the donor areas closed by sliding or skin grafting. Occasionally, the skin of the pedicle can be tubed in the same stage.

Stemless flap grafts are made by outlining the pattern on both donor and recipient areas according to a method described by Blocker.[8] Half of the pattern marked on the abdomen is freed and turned back on the abdomen. The two raw areas, that is, the flap which has been turned back and the donor site, which corresponds in size to the original defect, are sewed together about their peripheries. It is best to carry out the separation in two stages as the area attached to the hand cannot support an equal area of flap.

When a tube pedicle is used and it is difficult to hold the hand correctly, exact position is maintained by fixation in plaster of paris, as is done in cross-leg flaps. A tube pedicle is useful in conveying a pancake-like expansion of skin cut to pattern, but it must be prepared in several stages.

When a digit has to be discarded, it can be filleted and its skin, together with nerves and vessels, used to replace cicatrix in either the palm or dorsum of the hand, or on another digit.

When all the digits and part of the hand must be covered at once, the mitten method (by which all the fingers are sewed together before the pedicle is applied) is not always satisfactory because the pedicle skin which seems ample at first, undergoes so much shrinkage. The best plan is to prepare either a direct flap or a flap on the end of a tube pedicle, interdigitating it in several stages, so that it can be applied to all the fingers at once. When it is detached from the abdomen, the base of the pedicle is laid down on the hand.

## Primary Closure

When possible, primary closure of certain selected wounds is advisable. It is timesaving, keeps hands limber, and covers vulnerable structures that might otherwise undergo a long siege of infection and sloughing. Closure may

[8] Personal communication to the author.

be accomplished by sliding skin flaps from the dorsum of the hand and skin grafting the denuded areas. It was formerly thought dangerous to apply an abdominal skin pedicle primarily, as the fat in that region is so vulnerable to infection. Now, with chemotherapy, it may be done with all the advantages of early closure in keeping hands limber.

### Burns

For all but deep burns, resurfacing may be done under chemotherapeutic protection when granulation has occurred, or later, after a temporary thin skin graft has been used. A thin graft is a surer take on granulations, but a thick graft makes better skin. Fortunately, burns leave a good vascular base, as the damage is done from the outside inward, and free grafts will usually suffice. Since even a small clot of blood will spoil the perfection of a skin graft, it is best to reinflate the tourniquet after ligating the vessels until the pressure dressing is in place. After dorsal skin grafts have been applied, exercise should be started early to prevent stiffening of the hand.

Tendons, joints, or bones which have been burned, must later be re-covered by pedicle skin. It is not unusual to see middle finger joints tightly flexed and distal joints hyperextended after dorsal burns because the extensor tendon for the middle joint has been destroyed. A new tendon for this defect can seldom be supplied, and then only after the finger has been covered by pedicle skin and the joint is in good condition. It is usually best to force the joint, or osteotomize it to a position of semiflexion and to pin it there until it is arthrodesed. The hyperextended distal joint may be treated similarly. Deformed nails and matrices may be replaced by free skin grafts.

The severe contractures following burns result from the piling up of granulation tissue. The wound then either heals spontaneously, or the granulation tissue is covered by skin graft. Considering that granulation tissue is the "baby" stage of contracted cicatrix, all such tissue should be scraped away before applying a skin graft. Similarly, when reconstructing an old contracture from a burn, the deep, white layer of cicatrix beneath the skin which is the late stage of granulation tissue and the tissue which causes the contracture, should be entirely excised down to a good vascular, flexible bed. The contracture deformity will then yield, providing that certain deep, secondarily contracted structures be severed. A skin graft can then be applied with the hand in the position opposite to that of the original deformity.

## INJURIES OF BONES AND JOINTS

### *Bones*

In the hand centers in the Zone of Interior in World War II gunshot wounds of the bones presented serious problems. Fractures of the bones of the forearm, the metacarpals or the phalanges united in abnormal positions,

upset the natural mechanics of the member and resulted in strain, pain, and disability.

When the patient with a malalined or ununited fracture reached a hand center, simple splinting and traction which would have been sufficient for the initial injury were no longer adequate. The degree of disability might have been lessened by selective early treatment (see p. 30 ff.), but that period was now past.

Angulation in a limb from malunion or dislocation upsets the balanced tension of the muscles spanning from the forearm to digits, causing compensatory and opposite angulations of the joints serially down the limb. If the lower ends of the forearm bones are angulated volarward or there is dislocation backward or carpus, metacarpus, or metacarpals on the carpus, or malunion of the metacarpals from dorsal bowing, the consequent tightening of the long extensors in being stretched over these convexities hyperextends the proximal finger joints. This in turn tightens the long flexor tendons to draw the distal two finger joints into flexion. Correction of the alinement immediately restores muscle balance, allowing the hand and wrist to assume again the position of function. Angulation upsets the mechanics, causing the tendons to pull out of their normal course. Errors in rotation cause fingers to cross or diverge on flexion and overlapping results in adherent tendons.

*Bone Carpentry.* Physiologic bone carpentry is required in the correction of nonunion, malunion, and defects in the metacarpals and phalanges. The malalined bones should be disconnected and rejointed in their normal positions so that the fingers will flex and extend in their proper planes and fingers and thumb oppose each other. Bone position must be corrected so that tendons may move properly in straight courses and have proper angles of approach to joints, and to bring about normal leverage and proper muscle balance. Bone surgery is akin to fine cabinetmaking, and bone ends contacted inaccurately frequently result in nonunion, because each time a vascular bridge is formed it is sheared and broken, until efforts to repair are defeated and pseudoarthritis results. Bone surfaces approximating one another should be broad. If attempt is made to join the bones by making the bone layers too thin, even though they are dovetailed, bony union will not be achieved because of insufficient blood supply. All the principles of repairing bones in general apply to bones of the hand. The periosteum should be preserved with its attachment to the soft parts intact and if necessary some osteoperiosteal or cancellous chips can be laid around a fracture line.

In rejoining bones, following open operation, it is wise to consider one of two procedures or both of them: pin the bones firmly together, or insert a small bone graft.

*Stability by Pinning.* Very little splinting is required if bones are firmly pinned. Fine Kirschner stainless steel wires may be drilled through the bones. They drill well if cut off obliquely with a wire cutter.

Several wires are placed in different directions, through the metacarpals and carpus obliquely through the two portions of bone or graft, transversely pinning several metacarpals together through heads, shafts, or bases, or longitudinally down the center. The wires are usually not left protruding through the skin as movement leads to infection. They are clipped off just beneath the skin, to be removed under procaine hydrochloride with pincers as soon as union as shown by roentgenogram is apparent. Immobilization in plaster is advisable and necessary if the wire enters joints such as the carpus.

Hand bones are usually pinned tightly together by 2 pins crossed to prevent distraction. As the pins are inserted, bone ends should be clamped tightly together with 2 towel clips or special clamps.

*Bone Grafts.* In reconstructing hands throughout World War II bone grafts were needed and used frequently. Grafts hold bones in position by acting as a key and aid in assuring union. They are also used to fill in large defects. They may be small, flat chips chiseled from one of the long bones, preferably from the proximal half of the ulna which has already been prepared in the operative field and is convenient, or they may be from the tibia, rib, iliac crest or another finger bone.

Grafts of rib or iliac crest have the advantage that bone healing is firm in 5 weeks while the hard cortical bone of the ulna or tibia may require 2 or 3 months to heal. Graft from hard bone may be pointed at each end, shaped like a potato masher for medullary insertions at each end, or stepped at each end to use as an onlay. The center of the graft in each case is of the thickness of the shaft.

There are many ways of shaping and placing bone grafts in the hand, some by such close mosaic-like placements that pinning is unnecessary, but usually by firm fixation with Kirschner wires.

*Repair of Metacarpals.* Metacarpals were found to be malunited, buckled backward, shortened, or ununited from defects of head, shaft, or base. Excellent results were obtained in the nine hand centers of the Zone of Interior by grafting for such loss of shaft, using ilium or rib and temporarily pinning the structures subcutaneously with fine Kirschner wires. Some surgeons preferred to use the tibia or ulna for these grafts. Fixation was so firm that capsulectomies of the metacarpophalangeal joints could be done at the same time.

If many of the structures about the metacarpal are damaged, it is usually the better course to excise the entire ray, including the metacarpal, together with a block excision of the cicatrix around it. The finger should be conserved so that the skin might be laid over the dorsum of the hand to replace cicatrix. With the exception of the fourth, the base of an excised metacarpal should be preserved for attachment of the extensor tendons of the wrist, or this insertion should be transferred to the next metacarpal. In excising the metacarpal of a central finger (ring or long), the marginal metacarpal (index or little) is jogged over onto its base for bracing effect. This prevents rotation from

tipping of the joint axes, and resulting finger crossing on flexion. This jogging narrows and loosens the hand.

When a head is gone from either marginal ray, the whole ray except the base should be removed or else the proximal phalanx can be recessed to the metacarpal shaft. The intrinsic muscles should be reattached to the proximal phalanx of the next remaining ray. If they do not reach, a small strip of tendon graft should be added.

In the case of loss of a central metacarpal head, a cross bone graft may be thrust into the two adjoining metacarpals to keep them from rotating, or a new metacarpal head may be constructed by grafting the head and shaft of a fifth metatarsal. Enough ligaments should be carried with the head to form a new joint. An arthroplasty with one member of the joint a bone graft without articular cartilage is not successful.

Loss of base of a metacarpal may be corrected by bone graft, either resting it on or impaling it into the carpus.

#### *Joints*

Prevention and treatment of stiffened joints constitutes a big problem in war surgery of hands. If injured hands are allowed to remain swollen, immobile, and in the position of nonfunction, crippling is inevitable. Precipitation of fibrin from edema seals all movable parts and causes the waterlogged ligaments to become short and thick. The tissue becomes organized and we have a congealed hand in the position of nonfunction. The wrist is in flexion, the proximal finger joints are straight and stiff, the thumb is at the side of the hand, the metacarpal arch is flattened, and the digits are clawed.

This is largely preventable by keeping the hand in the position of function with as many of the joints as possible moving. Only the injured part should be splinted; the rest of the hand should be kept moving from the time of injury to discharge for duty. Swelling should be prevented by elevation, pressure dressings, prevention of infection, early closure of all raw areas, and mobility. For the position of function, the wrist should be kept dorsiflexed and the metacarpophalangeal joints flexed. These are the two key joints.

As soon as wounds are healed, the hand should be made to assume the position of function by elastic or spring splinting. This is most efficient in moving the joints around into the desired position.

*Metacarpophalangeal Joints.* These stiffen in a straight or hyperextended position as their two collateral ligaments shorten and thicken, thus preventing flexion. Prophylactically these ligaments may be kept long by maintaining the position of flexion. If eventually they do not yield to elastic splinting, capsulectomy is in order. This consists of excision of the two collateral ligaments subaponeurotically by splitting and rejoining the extensor tendons.

If by roentgenogram it is seen that the joint is too badly injured, arthroplasty is indicated. This is done usually at the expense of the metacarpal head

and shaping it so the phalanx will have a rocker effect on its transverse narrow end. A hood of fascia is grafted over the end of the metacarpal to separate the bones from each other and from the surrounding six tendons that pass across the joint. These tendons give a good stabilizing effect in arthroplasty.

Whether capsulectomy or arthroplasty is done, the metacarpophalangeal joints must be kept in flexion by rubber band tension for a long enough time to maintain flexion, even if this amounts to 6 weeks. Interosseous muscles must be functioning to maintain the flexion or the proximal pulleys of the flexor tendons must be slit.

*Middle and Distal Finger Joints.* Neither capsulectomy nor arthroplasty was usually done on these joints as they were less successful. Capsulectomy helped some but was usually not long lasting. After arthroplasty there was insufficient lateral stability as tendons were on only the back and front of these joints, in contrast to the multiple tendons about the proximal finger joints. For either procedure it was necessary that all other tissues about the joint to be normal. Arthrodesis or tenodesis was usually the procedure of choice.

*Wrist Joint.* The flexed wrist constitutes a disability. The position should be changed to dorsiflexion even though flexor tendon lengthening, capsulotomy, or arthrodesis may be necessary.

Arthrodesis in mild dorsiflexion gives a very serviceable wrist especially if there is pronation and supination. The latter may be spared by preserving the lower radial ulnar joint or by excising the head or neck of the ulna.

In some cases where motion of the wrist was desirable, arthroplasty by excising the proximal carpal row together with the head of the os capitatum resulted in considerable motion. In worse cases, both rows of carpal bones were excised. Motion and strength were then less. Eventually in some of these cases when arthritis ensued, arthrodesis would be necessary. When the ulna was cut off above the pronator quadratus muscle, a tendon sling was placed about the ulna and the tendon of the flexor carpi ulnaris to hold the ulna in place.

Follow-up treatment for stiffened hands after operative repair was mostly by occupational therapy. Physical therapy helped for a week or two and longer in paralytic cases, but occupational therapy or a furlough at work gave the best results (see section on Occupational Therapy, p. 68).

## CONSTRUCTION OF NEW DIGITS FOR PREHENSION

In cases of loss of the various digits, those remaining were brought around by rotary angulatory osteotomy so some would oppose others for prehension. Thus, if only the thumb and little finger remained, these could be made to work against each other, the osteotomies being through the bases of the metacarpals.

If the thumb was short and its cleft too shallow, it could be made relatively longer by a Z-plasty of its cleft and much wider by excising the index metacarpal through its base.

If all digits were off at their proximal joints, a useful hand could be gained by excising the second and fourth metacarpals, phalangizing the remainder by plastic procedures, and by osteotomies to permit the three separate digits to work against each other.

In cases of loss of the thumb, the index finger or what remained of it was pollicized so it would act as a thumb. This procedure was carried out in about 20 cases. The aim was to carry over nerve and blood supply and reattach tendons and thenar muscles to give the new thumb sensation and mobility. Proper positioning was essential. In these cases a movable stump of the thumb metacarpal was a great asset but not a necessity.

In other cases of total loss of a thumb, a serviceable digit for the fingers to act against was made by implanting a thumb post of bone into the radial side of the carpus and covering it with pedicle skin graft. Wherever possible, a pedicle of skin from the hand was placed to cover the tactile surface of the thumb for stereognosis. It was found that a short, immovable thumb with good sensation was very useful.

## INJURIES OF TENDONS AND MUSCLES

Surgeons were quite successful in tendon surgery, often getting good results in repairs in the forearm, over the dorsum of the hand, in the palm, and about the thumb. Repair of flexor tendons by grafts was, in general, fairly successful. Much depended on precise attention to essential principles. Stress was placed on sufficient gliding material, on atraumatic technique, and on placing tendon junctions where they would not adhere.

Successful function after tendon repair must be based on thorough knowledge of how tendons act following injury, their physiology, and also muscle balance, stabilization, and coordinated action. *Essentials for tendon repair are good nutrition of the hand, complete mobility of the joints, alinement of the bones for proper mechanics, and a soft bed for gliding.*

### Healing of Tendons

Tendon ends cut in a sheath remain free and merely rounded over unless infected, but when cut in paratenon they proliferate in an effort to reach the other tendon end and usually attach instead to surrounding structures. They should therefore never be left unsatisfied in wounds, or they will attach to firm parts and prevent movement. A large tendon end attached to a small one will do this unless fishtailed. One tendon woven through another does not unite well unless its unsatisfied end is imbedded in the other tendon.

Adhesions of tendons to surrounding parts prevent motion and like stiff joints, are caused by swelling and immobility. The fibrin precipitates, sealing the parts. They become organized and the tendons cannot glide. Tendons

contacting bone, passing through fascia, muscle, or through scar tissue always adhere.

If the flexor profundus tendon to one finger adheres, the common muscle will not be able to pull on the other fingers. If a tendon is severed, the muscle contracts and so loses its force and amplitude until accommodated for. Contraction of 2 months duration becomes fixedly so.

Tendons heal in 4 weeks. The first is the week of fibroblastic proliferation. The second is that of connective tissue proliferation, the third of tendon cell proliferation, and the fourth of resolution and cleavage for gliding. During these weeks the tendon is greatly swollen, but in the fourth week swelling subsides. The juncture is weak for the first 3 weeks, but after 1 month the danger of breaking is over. Up to 15 days there is the same strength whether the tendon is used or splinted. Thenceforward activity increases strength, but too much activity increases adhesions. Moderate graded activity from the beginning and strong activity after a month, seem to give the best results.

## Gliding Mechanism

It is useless to repair tendons in cicatrix since they cannot glide. Cicatrix must be excised en bloc, a good soft bed supplied and new cover provided if necessary by pedicle skin graft. Pedicle fat may be sandwiched around the tendons or they may be threaded through the fat. As an alternative, a gliding layer may be interposed between the tendons and the hard parts consisting of paratenon (thin gliding fat over triceps tendon or fat close to the deep fascia on the outer side of forearm or thigh where we rub against outside obstacles) or deep fascia with or without the thin layer of paratenon. A layer of paratenon may be wrapped around a tendon. Our aim should be to reconstruct a minimum of moving parts and a maximum of gliding material.

Synovial lined sheaths for tendon gliding have been formed by previously placing inert foreign bodies, best a ribbon of polythene, and a few weeks later removing the foreign body, placing the new tendon graft in the sheath. In another method a sheet of polythene is placed between the tendons and the hard parts. It is removed a month or more later.

## Tendon Grafts

In a third of tendon reconstructions, grafts were used. This was not only because the muscles had retracted, tendon ends had frayed, or the tendon was rough and adherent or degenerated from disuse. It was done so as to place tendon junctures at strategic places. Junctures are prone to become adherent to firm surrounding parts such as the narrow tunnel within a finger, the fibrous distal half of the palm, or under the transverse carpal ligaments. Therefore, the damaged tendon is replaced with a graft so that one juncture will be at the

distal phalanx where it does not have to move and the other either in the proximal part of the palm or above the annular carpal ligament of the wrist. Best results are secured from grafting a tendon plus its paratenon as a complete gliding mechanism. It can be obtained from the palmaris longus or long extensors of the small toes. The extensor brevis will carry on for the toe extension.

Tendon grafts of the size of finger tendons do well and soon look like normal tendons both in the gross and microscopically. Sources are palmaris longus, long extensor of small toes, one long extensor of a finger that by test can be spared, or a tendon from an amputated finger. A sublimis tendon can be used. Its epitenon furnishes some slippage. Preserved tendon grafts are not satisfactory as they adhere. A strip of fascia lata has unsatisfied edges so it also adheres.

*Within a Finger.* In the zone between the distal crease in the palm and the middle crease of a finger (*no man's land*), the juncture of a tendon always adheres after secondary repair. Here, therefore, a graft is necessary. The flexor sublimis is removed lest the tendons adhere to each other. The annular band or pulley is excised or split. In the repair a tendon swells. If it is encased in an annular band, its blood supply is squeezed out, rendering it ischemic, necrotic, and finally fibrotic. A tendon may be sutured in the middle segment of a finger as here it must pull through only one joint. In a thumb a tendon graft should reach to above the carpal ligament. The proximal juncture of a tendon in the palm may be surrounded by the lumbrical muscle which is its natural attachment.

Primary tendon suture in *no man's land* may be successful under the following precautions: The wound should be treated early by careful atraumatic debridement. The annular band or pulley should be slit through or excised to allow the tendon to swell and the sublimis tendon should be removed from the finger, severing it distally opposite the middle joint. Suturing is done at a distance in the palm with a pullout stainless steel wire (not silk) drawn down to a button on the plica of the palm for a period of 3 weeks. It must be sufficiently taut so that passive extension of the finger does not pull the tendon ends apart. These are merely laid together in place. If cut when the finger was flexed, the juncture will slip down the finger so as not to coincide with the wound. Such precautions minimize the chances for adhesions.

## Technique

To minimize adhesions, which are the obstacles to gliding, surgery should be done under ischemia from a pneumatic tourniquet and atraumatically. Hematoma and swelling are avoided by using voluminous fluff dressings under just the right pressure by an elastic bandage. Silk sutures and ties result in incapsulation of the silk with connective tissue (*silkoma*) which leads to adhesions. Stainless steel wire is the least irritating.

For insertions of tendons, No. 34 monofilament stainless steel wire is used, the suture spliced into the tendons is passed either through the tendon stub or the distal phalanx and out through the nail. Here it is made fast on a button or if over the nail to a small wire ring. A pullout wire is placed in the loop of the suture and brought out through the skin proximally. The suture and pullout wire must first be drawn back and forth through the tendon so it will withdraw easily. At the end of 3 weeks after the tendon has united physiologically and the suture is no longer needed, the button or ring is cut off and the suture removed backwards. If it does not withdraw easily, a small rubber band fastened to the pullout wire will remove the suture during the next 24 hours. In placing the suture, each tendon end is grasped by a hemostat and later cut off.

For the proximal juncture of tendons, fine flexible multistrand stainless steel wire is used and left in place. Being flexible it does not irritate the tendon mechanically, thus allowing for early motion. Two slender straight needles on a 10-inch suture are started ½ inch back from the tendon end and made to pass back and forth through the tendon in about the same plane, to emerge at its end. They are then continued on up the other tendon end to emerge together at the same point. The tendons will not slide down this suture until each end of the suture is tightened alternately. A single knot sinks into the tendon; the suture spliced along the length of the tendon and all being in about the same plane does not hamper the blood supply.

In the after treatment, the wrist, not the fingers, is held in flexion by a plaster of paris slab and a fluff pressure dressing is applied. Gentle, graded, voluntary finger motion is started next day and gradually increased for 3 and 4 weeks, after which the voluntary exercises are freely used, always holding the base of the finger so the tendon will move through the finger. Gripping a rubber sponge is useful as is closing the fingers over a flat wooden block with rounded edges so as to give a fulcrum over which the middle joints can act. Working the hands together in warm soapsuds is also beneficial but actual manual work is the best. Improvement in movement continues for a year.

### Tendon Transfers

*Mechanical Considerations.* (1) There are 7 wrist movers: 2 extensor carpi radiali, 2 ulnari, a flexor carpi radialis, a palmaris longus, and the abductor pollicis longus. (2) There are 18 digit movers: 9 extensors—6 to fingers and 3 to thumb; 9 flexors—8 to fingers and 1 to thumb. (3) There are 20 intrinsic muscles: 7 to thumb, 4 to little finger, and 9 to the other fingers.

*Stabilization.* When we reach out to grasp or pinch, muscles from trunk to wrist tense to hold out the arm so that the hand may work. When then we grasp, the wrist must be stabilized both by its extensors and flexors. The extensors stabilize it in dorsiflexion so that the digit flexors can make a firm grip, and by its flexors so that dorsiflexon will be curtailed enough to allow the fingers

to completely extend. Similarly in the fingers the long extensor tendon must hold the metacarpophalangeal joint in the extended position in order that the intrinsic muscles can straighten the distal two finger joints. Also the intrinsic muscles must hold the metacarpophalangeal joint in flexion so that the long extensor muscles can extend the distal two finger joints. When we pinch with the thumb, the carpometacarpal joint must be held in extension by the abductor pollicis longus, and the metacarpophalangeal joint in flexion by the short adductors of the thumb, so the long flexors can act with proper mechanics on the distal joint. Only when the joints proximal in the limb are firmly stabilized can the digit movers act properly on the digits.

*Muscle Balance.* There is a nice muscle balance between the long extensors, long flexors, and the intrinsic muscles of the hand that naturally holds that member in the position of function. Flexion of the wrist or extension of the metacarpophalangeal joints of the fingers so affects this balance that the hand claws in the position of nonfunction. Thus, the wrist is the key joint of the hand and the metacarpophalangeal joints are the key joints of the fingers. For the rest of the hand to function properly they must be stabilized in the position of function.

In movements of the hand the many muscles (45) coordinate so beautifully with each other, all playing a part, that there results unexcelled refinement of motion of this versatile organ. They also synchronize, some executing one part of the motion and others the remainder.

*Principles.* Tendon transfers are done to correct conditions resulting from paralysis or destruction of some muscles or tendons. They may be combined with arthrodeses and tenodeses. The following principles must be observed:

1. The deformity must first be corrected by osteotomy, capsulectomy, muscle stripping, excision of scar, or pedicle graft.

2. The transferred muscle must be red and healthy and have adequate strength. It must be strong enough for muscle balance, else the deformity returns. If it is too strong, the deformity will be overcorrected. By advancing an insertion, additional leverage can be given.

3. For full motion the muscles should have adequate excursion. Excursion of wrist movers averages 1¼ inches, digit extensors 2 inches, and digit flexors 2⅞ inches. The same tendon should not be used to move all three extensors of the thumb as the long extensor will be held back by the small amplitude of the abductor pollicis longus.

4. The tendon must glide. If it passes through cicatrix, fascia, muscles, or contacts raw bone it will adhere. Tendon junctures should not be placed in finger or carpal tunnels. Paratenon or fat from a pedicle skin graft may be placed beneath the tendon or some deep fascia may be turned over to give a gliding surface such as for an ulnaris muscle.

5. A tendon should pull a straight course. If it turns around a pulley its muscle should be stronger.

6. Tension should be adjusted for the best part of the muscle range and the most useful arc of the movement of the limb, this with due calculation for balance, stabilization, and shortened muscle.

7. Allied function to a reasonable degree is not so important in a hand since the brain accommodates within limits. One muscle should not have two functions unless they are allied. Postoperatively some patients can move the transferred muscle correctly at once and some must first tense the limb and need instruction before the movement becomes natural.

Cases differ so each must be planned separately. A good working plan is to list first the number of actions needed, then the number of muscles available, and finally to distribute these to the best advantage.

If tendons have allied functions and excursion, a slip from one may be used to activate the other. Thus, the abductor pollicis longus may be activated by a slip from either the extensor carpi radialis or flexor carpi radialis.

In certain transfers the activating tendon may not lose its function such as pronator teres to extensor of the wrist, flexor carpi ulnaris for opposition, flexor or extensor carpi radialis to abductor pollicis longus if the pulley of the latter is slit, and extensor pollicis brevis for opposition.

### *Arthrodesis*

In order to move the digits it may be necessary to stabilize the proximal joints in the hand by either tendon transfer, arthrodesis, or tenodesis. When there are not enough tendons available, arthrodeses are useful.

Wrist fusion results in very little disability, especially if the end of the ulna is free for pronation and supination. It makes five tendons available for transfer to the digits. These will give full amplitude of motion to the digits as part of their excursion will no longer be used up by the wrist movements.

If any two nerves are paralyzed high (above the branches of the forearm muscles) the wrist should be arthrodesed. Whenever there are not enough muscles to go around, the wrist can be ankylosed. The hand may be pronated or supinated to the position desired by arthrodesing the radial-ulnar joint and the thumb may be held in opposition by a bone graft, arthrodesing between the first and second metacarpals.

Arthrodesis may be done on any joint from shoulder to fingertip, but not on too many joints because it will stop the movement and subject the bone to fracture. The rule is to arthrodese enough joints to place the arm and hand in the position of function and allow the available tendons to give prehension.

### *Tenodesis*

In the leg, tenodeses, unless massive as with the Achilles tendon, eventually yield. However they are useful in the nonweight-bearing upper extremity.

In planning an extensive hand reconstruction, we should weigh carefully the results to be obtained from tendon transfer, arthrodesis, tenodesis, or a combination of these.

Tenodeses spanning the wrist are especially useful when there are too few muscles available to combine with arthrodesis. There must, however, be either a strong extensor or flexor of the wrist.

With one strong wrist extensor as in paralysis between 6 & 7 C, if the flexors of the digits could be tenodesed to the radius and a pulley operation done for opposition of the thumb, tenodesing the tendon to the ulna just above the wrist, the patient can by extending the wrist flex his digits for grasping and oppose his thumb. The supinator longus can be added to supplement with some voluntary flexor action.

In radial palsy if the extensors of the five digits are tenodesed to the radius, a wrist flexor can extend the five digits. If then there are digit flexors they can make the wrist dorsiflex by flexing the digits. These automatic motions are very useful. If the distal joint of a finger bends backward without support due to loss of the profundus muscle, it can be tenodesed in slight flexion.

### *Special Transfers*

*Radial Palsy.* Five actions are needed and four muscles are available. Those needed are to stabilize the wrist in both dorsiflexion and palmar flexion, to extend the proximal finger joints, to stabilize the carpometacarpal joint of the thumb, and to extend the thumb.

Available muscles are flexor carpi radialis, palmaris longus, flexor carpi ulnaris, and pronator teres.

The wrist must be stabilized in dorsiflexion by either transferring the tendon of the pronator teres into the extensor carpi radialis tendon or by arthrodesis. Otherwise when the digits are flexed it will go into flexion and there will be loss of grip. The wrist should maintain at least one flexor, the flexor carpi radialis or palmaris longus, or it will dorsiflex at the expense of finger extension.

If the flexor carpi radialis or palmaris longus is made to activate the abductor pollicis longus, the pulley of the latter should be slit through so that these muscles will also flex the wrist.

In order to pinch, the thumb should be stabilized in extension at the carpometracarpal joint by activating the abductor pollicis longus by a slip from the extensor or flexor carpi radiali or by the palmaris longus, slitting the pulley for flexion of the wrist if either of the latter two are used. Another method is to stabilize this joint by arthrodesis.

The extensor or flexor carpi muscles are too strong to attach to the extensor pollicis longus. The amplitude of the wrist movers is too short to expect them to move both wrist and digits to full degree. These transfers for radial palsy therefore extend the fingers when the wrist is only slightly dorsiflexed and flex them when the wrist is only slightly palmar flexed. When the wrist is arthrodesed, however, the digits will have a full range of motion but arthodesis is not done for the average case of radial palsy.

## History

Murphy [9] in 1914 saved the ulnaris and used the flexor carpi radialis to extend all digits. Starr [10] in 1922 did the same but used the palmaris longus to activate all three thumb extensors. Jones [11] in 1921 used both flexor carpi radialis and ulnaris and used the pronator teres to dorsiflex the wrist. He left nothing to flex the wrist. Zachary [12] in 1946 found that in one-fifth of the cases the wrist dorsiflexed, but the fingers could not extend unless some flexors of the wrist were left in place.

## Some Examples of Transfers for Radial Palsy

1. Flexor carpi ulnaris to extend three digits; flexor carpi radialis to long extensor of the thumb and of index; and the pronator teres to extensor carpi radialis to dorsiflex the wrist.

To activate the abductor pollicis longus, a slip of tendon may be transferred from the extensor carpi radialis, or the flexor carpi radialis or the palmaris longus may be used. If either of the latter are employed, the pulley of the tendon of the abductor pollicis longus should be slit through so as to give some flexion to the wrist.

2. Flexor carpi ulnaris is transferred to the extensor tendons of all fingers; palmaris longus is transferred to the long extensor of the thumb; the flexor carpi radialis is transferred to the abductor pollicis longus (slitting pulley); and the pronator teres is transferred to the extensor carpi radialis.

*For Paralyzed Dorsal Interosseus Nerve.* Extensor carpi radialis brevis is transferred to all long extensors of the five digits.

To activate the abductor pollicis longus a slip is transferred from either the extensor carpi radialis longus or the flexor carpi radialis, or the palmaris longus is used.

*For Median Nerve Palsy.* If high (above branches to flexors in forearm), it is necessary to flex the first three fingers and to flex and oppose the thumb.

Available are one extensor carpi radialis, the part of the flexor digitorum profundus supplied by the ulnar nerve, the supinator longus, and the extensor carpi ulnaris.

All fingers may be flexed by the flexor digitorum profundus supplied by the ulnar nerve and also reinforced by the supinator longus.

The extensor carpi radialis longus can flex the thumb and either the flexor or extensor carpi ulnaris can be used to furnish opposition of the thumb.

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[9] Murphy, John B.: The Clinics of John B. Murphy, M. D., vol. 3, No. 7. Philadelphia, W. B. Saunders, Jun 1914.

[10] Starr, C. L.: Army experience with tendon transfer. J. Bone & Joint Surg. 4: 3–21, Jan 1922.

[11] Jones, R.: Tendon transplantation in cases of musculospiral injuries not amenable to suture. Am. J. Surg. 35: 333, Nov 1921.

[12] Zachary, R. B.: Tendon transplantation for radial nerve paralysis. Brit. J. Surg. 33: 358–364, Apr 1946.

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*For Ulnar Palsy.* The index finger may be given the power of abduction which produces a much better pinch, by transferring to the lateral band on the radial side either the extensor indicis proprius, the extensor pollicis brevis, or its sublimis tendon withdrawn at the wrist and passed subcutaneously over the dorsum of the hand to the lateral band.

The profundus tendons supplied by the ulnar nerve should not be activated by the profundus tendon supplied by the median nerve as this would increase the clawing.

The sublimis tendons should not be used for finger balance in ulnar palsy as the ring and little fingers would then have no flexor, their profundi being paralyzed.

*For Median Plus Ulnar Palsy.* High (above the branches to the flexors in the forearm)—arthrodese the wrist.

Low—do not arthrodese the wrist.

In high severance, we need to provide flexion to five digits, to adduct and oppose the thumb, and to establish muscle balance in the clawed fingers.

Available are four muscles, two extensor carpi radiali, the extensor carpi ulnaris, and the supinator longus.

In low severance (see Intrinsic Muscles).

*For Ulnar Plus Radial Palsy.* Fuse the wrist, and use flexor carpi radialis to extend the thumb and index finger. Use pronator teres prolonged by a tendon graft to extend the last three fingers, the palmaris longus to abduct the thumb, and the sublimi for muscle balance in the fingers.

*For Median Plus Radial Palsy.* Fuse the wrist. Do what is needed to oppose the thumb, flex the digits, and extend the digits.

*For Deformity of Pronation.* Sever the pronator teres and pronator quadratus. Transfer flexor carpi ulnaris around forearm to insert on the radius and add pronator teres to this. Otherwise you may fuse a radio-ulnar joint in the desired rotation or rotate the ulna by osteotomy.

*For Paralysis Between 6 & 7 C.* (See Tenodesis.)

*For Paralysis Between 7 & 8 C.* Needed are flexion of five digits, opposition of thumb, abduction of index finger, and correction of the clawing of the fingers. Use:

Extensor carpi radialis brevis to flex the thumb.

Flexor carpi radialis longus to flex all fingers.

Flexor carpi ulnaris, if present, to give opposition.

Supinator longus for whatever else is needed, such as muscle balance in fingers through the sublimis tendons.

Extensor indicis proprius to abduct the index finger. The proximal pulleys of the fingers should be advanced.

*For Lower Brachial Plexus Palsy.* Arthrodese the wrist.

Extensor carpi radialis longus and brevis, flexor carpi radialis, and the supinator longus are available for flexion of the digits and to substitute for the action of the intrinsic muscles.

## Intrinsic Muscle Palsy

Paralysis of the intrinsic muscles of the hand results from injury to the median and ulnar nerves but not from that to the radial nerve. It is usually corrected by transferring the tendons of the long forearm muscles. The tissues and joints must be soft and pliable. Such treatment is seldom applicable after infection. If the median and ulnar nerves are injured high above the branches to the forearm muscles, the wrist is first fused. Then needed are flexion of five digits, adduction and opposition of the thumb, and correction of finger balance.

Available are two extensor carpi radiali, the extensor carpi ulnaris, and the supinator longus.

If the nerves are injured low (below the branches to the forearm muscles) the wrist should not be fused but only transfers should be done for the intrinsic paralysis namely for adduction and opposition of the thumb, curvature of the metacarpal arch, muscle balance in the fingers, and to abduct the index finger.

### *Opposition of the Thumb*

In complete opposition, the thumb normally reaches to 3 inches in front of the base of the long finger; the nail is then parallel to the palm. Too often an operation is done with the transferred tendon passing through the carpal tunnel under the transverse carpal ligament which draws the thumb into the palm in apposition only.

The activating tendon should insert on the ulnar side of the base of the proximal phalanx, pass directly over the metacarpophalangeal joint, then subcutaneously across the thenar eminence in the direction toward the pisiform bone. This gives true opposition. One can then use any muscle, any tendon, and any pulley as long as the above principles are used. According to circumstances, one may choose for a muscle the palmaris longus, the sublimis of the ring finger, and flexor carpi ulnaris, or the extensor carpi ulnaris. For a tendon, one can use that of the extensor pollicis brevis leaving its original insertion intact but slit slightly distalward; the tendon of the sublimis of the ring finger which just reaches; or may place a new tendon graft. For a pulley, the tendon may be looped about that of the flexor carpi ulnaris to give the right direction of pull; a pulley can be made from a loop of free tendon graft, or one may use the extensor carpi ulnaris with its direct pull and so obviate a pulley. If the flexor carpi ulnaris happens to be paralyzed, it will yield. To avoid that contingency this tendon should be tenodesed to the ulna. The ulnari are the strongest muscles but the sublimis has the longest amplitude. As in most transfers, the

tendon should be attached slightly on the tight side. If there are no tendons available, opposition may be maintained by arthrodesing a wedge-shaped bone graft between the first two metacarpals.

#### *Adduction of Thumb and Curving of Metacarpal Arch*

For this a tendon T operation is useful. First the tendon graft is made to span from the head of the metacarpal of the little finger across the palm beneath the tendons to the adductor tubercle of the proximal phalanx of the thumb. Then a tendon of one of the long flexors is looped over its center to form a T. On pulling, the T changes to a Y, the metacarpal arch curves, and the thumb adducts.

#### *To Furnish Abduction to the Index Finger for a Better Pinch*

Abduction can be furnished to the index finger by transferring to the lateral band of the finger either the extensor indicis proprius, extensor pollicis brevis, or the sublimis, as explained above.

#### *To Restore Muscle Balance in the Fingers*

From loss of lumbrical and interosseus action the metacarpophalangeal joints extend or hyperextend and the distal two finger joints flex. Lateral motion is lost and it is necessary to flex the metacarpophalangeal joint and extend the distal two finger joints, thus changing from the intrinsic minus position to the intrinsic plus position. For this the four sublimis tendons are disconnected at their insertions, releasing the flexion contractures of the middle finger joints. The sublimi are withdrawn into the palm and each then passed down a lumbical canal and made to insert on the lateral band of the dorsal aponeurosis with the finger in the intrinsic plus position. To give lateral motions, each sublimis may be slit and each end inserted on the radial or the ulnar lateral band of the adjoining fingers. Practically, it is sufficient to insert just four tendons each to the radial lateral band and one to the ulnar lateral band in the little finger.

Similarly each extensor proprius may be slit and transferred to the lateral bands. The two marginal ends should be looped around, one about the insertion of the first interosseus muscle and the other about that of the abductor minimi digiti. The two central slips should pass through the interosseus muscle anterior to the transverse metacarpal ligament and insert on the lateral bands. The proprius muscle action is then weak and works more as a tenodesis to keep the proximal finger joints from cocking backward.

If there is high ulnar palsy, the sublimi must not be used as the profundi will not be functionating.

#### *Claw Hand*

This deformity is due to paralysis of the median and ulnar nerves. It results from muscle imbalance and is due to the action of the long extensors

and the long flexors uncontrolled by the muscle balancing action of the intrinsic muscles of the hand because of their paralysis. The thumb is drawn to the side and rear of the hand. The proximal finger joints are cocked back and the distal two finger joints are flexed.

The deformity is less in high paralysis as the paralyzed long flexors do not produce much clawing. It is greater in low paralysis as here they are active and claw the fingers. It is greatest when the long flexors are adherent in the forearm and thus produce extreme and unyielding clawing.

In claw hand the proximal finger joint is the key joint of the finger. If this hyperextends clawing is extreme, but if this joint is passively flexed to the straight or slightly flexed position, the shortened long extensors can then extend the distal two joints of the fingers. Therefore, this metacarpophalangeal joint must be kept straight or slightly flexed.

This may be done by a bone block, sliding the back of the head of the metacarpal distally; by a tenodesis operation such as described above for the extensor proprius tendons, or a tenodesis effected by a free tendon graft from a lateral band across the volar aspect of the proximal finger joint which after passing through the interosseus muscle is fastened to the dorsum of the hand to an extensor of the wrist or to the bone. This does not give positive flexor action to the metacarpophalangeal joints. It is necessary to slit the proximal pulleys to allow the long flexor tendons to displace forward and so gain an angle of approach to the proximal phalanges to give positive flexion to the metacarpophalangeal joints. This becomes necessary because of loss of action of the intrinsic muscles.

The basic tendon transfer to flex the metacarpophalangeal joints and extend the distal two is to disconnect the sublimis at its insertion, withdraw it into the palm, thread it down through the lumbrical canal, and attach it to the lateral band. This also relaxes flexion contracture of the middle finger joints.

If long flexors are adherent in the forearm, adhesions should be excised and a fascial graft made to separate tendons and bones.

Another procedure is to arthrodese either the metacarpophalangeal joint or the proximal interphalangeal joint. Either of these helps the tendon to flex the other joint. Arthrodesis of the metacarpophalangeal joint helps the overflexion of the proximal interphalangeal joint, but a sublimis transfer is necessary to extend the distal two finger joints.

## VASOMOTOR AND TROPHIC CONDITIONS

There is a type of individual with dysfunction of the vasomotor nervous system and a tendency to neuroses. These persons show fine tremor, sweaty hands, nervousness, and a low threshold to and a phobia of pain. The injured hand is atrophied, edematous, and often fixedly stiffened in all of its tissues

in a semiflexed position. This condition has resulted from continued protection and disuse. Roentgenograms showed osteoporosis throughout but especially about the metacarpophalangeal joints and in the carpus. An increased blood supply had carried away the lime. A vicious circle was established. The more the protection and disuse, the greater was the atrophy and porosis. Sympathy and physical therapy by evil suggestion intensify and fix the condition which is called minor causalgia or Sudeck's atrophy.

Patients of this type may be recognized early and treated prophylactically. They should be made to use the hand constantly, doing chores in the ward and performing regularly a full day's work in occupational therapy. Helpful suggestive treatment builds up character, confidence in their own independence and an optimistic point of view. Without this, many men even alienated the hand from control of the brain. With compulsory work the condition can be avoided. Repeated sympathetic blocks of the second and third dorsal ganglia are helpful but actual use of the hand is even better.

Amputation stumps in hands may be extremely hypersensitive from painful neuromata. This may establish such a pain habit that it persists after repeated amputations. When a nerve is cut off in infected tissue or cicatrix, it frequently forms a painful neuroma, the axones penetrating into the scar, but if severed high in normal tissue and away from sites of trauma it usually does not. After one good revision for painful amputation stump excising all scar, furnishing good soft cover, and severing the nerve high in good tissue, further surgery is usually inadvisable.

Causalgia is the dystrophy in which pain, not edema, is paramount. The pain shoots spontaneously from emotional causes as well as on touch. This is not an entity but a severe special grade of vasomotor dysfunction in which the vasomotor system plays a major part. Prolonged use of the hand has cleared up some cases but the most success was obtained through sympathetic blocks of procaine hydrochloride. When these were not entirely successful, preganglionic sympathectomy of D 2 and D 3 achieved a permanent cure in most cases.

## SPLINTING

### *Reasons for Splinting*

We splint either for immobilization or to draw the joints around into position of function. For the first we use rigid, for the second, active splinting.

We immobilize in treating infection, for holding fractured bones, or for better healing after trauma or surgery. The limb is held in certain positions by splints to protect newly repaired tissues such as tendons, nerves, and ligaments from breaking, to keep paralyzed muscles in relaxation, and in other cases to allow the tissues to grow until they adapt themselves to the desired position. Splints to immobilize should be form fitting and in broad contact with the limb. This should encircle, especially at the joint and at the two ends of the longest possible lever arms.

We gradually draw joints into more flexion or extension in order to correct deformities, to place the limb in a position of function, or to give more motion to a joint. To draw joints into flexion and extension the splints should have 3 padded areas for broad pressure: 1 at the level of the joint as a fulcrum, and the other 2 on the opposite side of the limb as far from the fulcrum as possible so as to give maximum leverage. Spring or elastic splints are preferred for this because they exercise the limb, keep the joints mobile, and are quickly effective.

Splints for paralysis need not, as formerly thought, maintain a paralyzed muscle in maximum relaxation by approximating its origin and insertion. In the past paralytic patients have been oversplinted. The former dictum was to keep the paralyzed muscles fully relaxed by splinting unremittingly in the position opposite that of the deformity. So many hands were thus crippled from overcorrection and stiffened from rigid splinting that some neurosurgeons began to reject all splinting in cases of paralysis. It is necessary merely to keep the muscles balanced in a position of function and to encourage use. An elastic or spring splint of strength equal to that of the former tone of the muscles now paralyzed and acting only on those joints that were influenced by those muscles is all that is necessary. The splint should be as light as possible and should allow free, unhampered use of the hand for manual work.

To splint for radial palsy (Figs. 11 and 12), the wrist should be held in moderate dorsiflexion, the proximal finger joints in extension, and the thumb with its proximal joints in moderate extension. The Thomas suspension splint is the best for this as it allows the best function, though the Oppenheimer splint is often used.

In median and ulnar paralysis, the claw hand, flat hand, and thumb at the side position can be corrected by light plaster splint, but a knuckle bender is better as it allows motion. The proximal finger joints are pushed into flexion, the metacarpal arches curved, and the thumb drawn into opposition.

For ulnar palsy, when needed, a light plaster splint to hold the proximal joints of the ring and little fingers in flexion can be used; still better are leather cuffs placed over the proximal segments of these fingers and drawn by light rubber bands to a cord at the wrist.

## Improper Splinting Is Harmful

Hands are prone to stiffen. The joints are accurately fitted and joint ligaments are just long enough for their purpose and no more. Immobilization of a limb causes atrophy and edema. If for any cause, a hand remains swollen and immobile for a considerable length of time, the serum-soaked ligaments become short and thick and bind the joints. From the fluid of edema, fibrin settles between and within the movable tissues, muscles, tendons, and joints alike. Fibroblasts invade. The whole structure becomes organized and then shrinks

to the familiar congealed hand. Rigid splinting is therefore dangerous if kept up for too long a time. Great caution is needed in using it.

Splints cause stiffness of the hands if they extend beyond the distal crease in the palm to include the digits (Fig. 1 B), if they are kept on too long, if they hold a joint in a rigid, strained position, or if they hold the hand in a position of nonfunction (Figs. 1 and 2). Errors of position in splinting are to hold the wrist flexed, the fingers straight, the palm flat, and the thumb at the side of the hand or pressed close to it.

The straight splint, the flat splint, and the banjo type (Figs. 1 and 2) should never be used. All of these throw hands out of alinement and stiffen them in malposition. Only rarely and for a special purpose should a plaster cast ever extend beyond the distal flexion crease in the palm or beyond the thenar crease, and only under similar special circumstances should it include all of the fingers to their ends. The wrist should be in 30 degrees of dorsiflexion and the plaster curved in the palm to preserve the transverse metacarpal arch.

## Characteristics of Good Splints

Splints should be simple, efficient, inexpensive, light, not offsensive to the patient, and easily adjustable. They should not be elaborately nor cumbersomely contrived with cuffs, straps, or too much machinery.

Splints should allow function (and always maintain the position of function) unless contrarily indicated.

## Fitting Splints

The forearm piece should fit the forearm whether it is on the volar or dorsal aspect. If it is on the dorsal side, a hollow should be made to protect the head of the ulna from pressure. The elbow should be allowed to flex fully, with no interference of the splint in the flexion crease.

The palm piece should comfortably fit the metacarpal arch and allow the proximal finger joints to flex to a right angle.

A dorsal hand splint should be curved transversely to fit the back of the hand and not impinge at the wrist on dorsiflexion.

Finger splints should follow the natural curve of fingers when semiflexed; thumb splints likewise; they should also hold the thumb in moderate opposition.

If any parts of the splints are to be movable, the pivots of such parts should coincide exactly with the centers of movement of joints, and the surface of the two and segments of the splint should ride the finger or hand segments perfectly throughout the complete movement.

There should be no tight encircling of the hand, and obviously no blanched areas where circulation is decreased, lest ischemic contracture develop.

## Splinting With Plaster of Paris

No splint is as effective as nonpadded plaster of paris. Padded casts fail to immobilize and cause pressure sores. The padding becomes displaced so the pressure of the cast is on a few bony prominences instead of being evenly distributed. Applying the plaster circularly and with some tension is to be condemned because of the danger of pressure sores, ischemia, or gangrene.

Plaster is laid on a limb in flat slabs and when a little over half the circumference of the limb is covered an encircling bandage is used to mold it in place. When the first layer is fairly hard, the gauze is cut its full length longitudinally along the limb to avoid constriction. A layer of wax paper, cellophane, or sheet wadding is then laid over the limb, and the back half of the cast is applied as a flat slab over it. Another gauze bandage is then wound over all. This bivalve is for safety so that in case the limb swells the lid can be lifted off and replaced after spreading the cast. The plaster should be molded to the curvature of the limb and around any bony prominences. The head of the ulna and the internal epicondyle should be especially protected. The term "skin tight casts" should not be used as it misses the principle and so will lead to gangrene.

In encasing the hand or fingers multiple small folded strips of plaster may be used instead of a large slab. They fit the contours better and reinforce the cast wherever needed. One thicker strip is used to complete the cast by passing across the cleft of the thumb and the palm between the thenar and distal palmar creases. It is made strong enough to withstand use and narrow enough to allow free motion of the thumb and proximal finger joints.

In the palm the cast should end with a thick edge for wear—not a feather edge—and should stop at the distal palmar crease so that the proximal joints of the fingers are free to flex (Fig. 74). All uninjured digits should be free to move and be kept moving.

A cast on the hand should either extend well up the forearm for good leverage, immobilizing the wrist, or stop at the base of the hand so the wrist will be free in all its motions.

There are several special uses of plaster of paris in splinting the hand. After repair of nerves, a dorsal slab enclosing two-thirds of the circumference of the limb may be used to hold the elbow and wrist in flexion.

Freshly repaired flexor tendons are protected by placing a dorsal slab of plaster to hold the wrist in flexion.

To protect repaired extensor tendons a volar slab is used to hold the wrist and digits in extension. Such slabs should be crowned sufficiently over the joints to be firm.

Following plastic operations on the hand or forearm the hand may first be fixed on a padded metal splint, then a voluminous fluff dressing applied under an elastic bandage. A broad slab of plaster is now placed over all to

insure immobility. Such a fluff dressing greatly lessens the danger of constriction.

To immobilize the wrist there is nothing better than form-fitting plaster of paris. This will even maintain lateral deviation of a wrist, and if non-padded will hold immobile a fracture of the wrist or the lower end of the radius. To stop pronation and supination, the elbow must be placed at a right angle and the splint carried to the axilla.

## Danger of Tight Cast

Swelling in tight casts, either postoperatively or after trauma, leads to catastrophe. Volkmann's ischemia is caused especially by pressue on the veins in the antecubital space, so all elbow casts should have complete freedom in the crease of the elbow. It is well first to lay a fluff of sheet wadding along the crease and to apply the plaster in such a way that this region will be free from pressure. Movement of the elbow while the plaster is setting works a plaster ridge into this crease. In relieving pressure which develops in a right angle elbow cast, two midlateral cuts should be made the full length of the cast and the front half should be lifted from the rear half through its full length. A right angle cast will not spread in both arms of the angle at the same time from one full length longitudinal cut. If the cast is applied following an injury or an operation, the hand should be elevated for several days.

Volkmann's ischemia is also caused by swelling occurring in casts about the upper arm or forearm. Pressure sores about the wrist and in the antecubital space often accompany it. Ischemic contracture, local in the hand, with or without pressure sores, follows swelling in the hand that is enclosed in a tight cast and also from constriction higher in a limb.

Frequent inspections are imperative as there is always danger of pressure points, ischemia, or gangrene. If the beginner is not taught this, he will learn it after bitter experience and will ever after be on the alert to ease constriction and pressure by slitting bandages to the skin the full length of the limb and spreading casts.

The digits should be exposed to view when a cast is applied to ascertain the condition of the circulation. Painful, cold, cyanotic, anesthetic swollen tips of an extremity, with loss of motion are the danger signs. A finger which has been operated upon must swell and needs relief. Casts should be bivalved as described above. An intervening sheet of wax paper or cellophane is preferable to petrolatum for later ease in separating the halves of the bivalve.

## Active Splinting

The wrist is the key joint in the position of function. In the position assumed by a sick hand, the wrist is flexed, the extensors of the digits are

tightened, the proximal joints of the fingers are hyperextended, the thumb is drawn back and to the side, and the metacarpal arch is flattened. Tightening of the flexors produces clawing of the fingers. The intrinsic muscles are then too far off center to act and shortening from disuse exaggerates the effect. The muscles are not in balance in this position of nonfunction but if the wrist is dorsiflexed they will be.

In the examination of many patients returned from overseas with their hands in plaster, it was unusual to find a dorsiflexed wrist. The hands found limber were those in which the wounds had been closed quickly, in which only the injured part had been immobilized, and that for but a short time, in which the position of function had been maintained with the proximal joints in flexion, and in which movement had been active and continuous.

If the hand has stiffened in the position of nonfunction, the best method is to force the joints around to the position of function by elastic or spring splinting. Hands are peculiar in that joints and moving parts are so accurately fitted together that they are prone to stiffen. This is the prevalent trouble following injury, infection, or operation. If we splint swollen hands on immobile splints, they will stiffen; if we use elastic or spring splints, they will not. Hands kept moving will not stiffen. Hands need motion to thrive. Rigid splinting makes rigid hands.

In forcing joints into other positions, spring or elastic splinting has been found to be more efficient than unyielding splinting. In splinting with springs or elastics the joints are never strained to excess nor are they immobilized. Active splinting is physiological splinting. It is normal for hands to keep moving. The hands work continuously against the springs or elastics and with these splints they are actually exercised. By this system we splint to mobilize, not to immobilize. It is functional splinting. The muscles pump away their stagnant fluids, washing out the toxins; the tendons keep gliding and the joints keep moving, thus preventing the formation of adhesions and maintaining mobile articulations.

Splints used in active splinting should be light enough not to interfere with occupational therapy or other work. Those to correct nonfunction should be so constructed as to draw the joints into a position of function. With the hand in the position of nonfunction a little motion is useless; with the hand in the position of function, the same amount of motion is useful for pinching and picking up objects. A hand which can do this will be called upon to do more and more, and improvement will continue as activity is increased.

To dorsiflex the wrist, a cock-up splint (Fig. 3) with a long flat spring is preferred. To this may be screwed a small outrigger with a metal tube roller, over which rubber bands extend from leather cuffs over the proximal finger segments to a hook in the belly of the splint. Thus, the key joints of the fingers, the metacarpophalangeal, are flexed.

Another excellent device for this purpose is the knuckle bender splint (Fig. 6) alone or in combination with a spring cock-up splint, or the wire Oppenheimer splint to work on both of the key joints simultaneously. The distal two joints of the fingers may be extended by using an outrigger attached to the knuckle bender over which rubber bands pass (Fig. 13). A free-turning tubed roller on the outrigger permits the rubber bands to work through their full length. The thumb is brought into opposition by attaching to the splint a leather cuff drawn by rubber bands in the direction of the pisiform bone.

In using plaster of paris when metal splints are not available, the plaster strips are placed on the forearm and hand. Outriggers are therein imbedded, and rubber bands run from them to the digits. To flex the proximal joints, the outriggers and rubbers are placed on the volar side. To extend the distal two joints, a flat slab of plaster is applied to the dorsum of the forearm and hand and also over a layer of felt over the proximal finger segments for a fulcrum. Leather cuffs and rubber bands running over the roller of an outrigger from the cast draw the distal two finger joints into extension.

## Finger Splints

Gutter splints for digits and hands may be made from plastic or any easily malleable material. They may be cut to pattern to hold finger joints in flexion and the thumb in opposition or for the particular purpose required. Sharp corners should be rounded off.

To extend a finger, a safety pin splint (Fig. 9) or a clock-spring splint (Fig. 10) of spring wire is useful. To flex fingers, broad rubber bands about the fingers and hand serve quite well.

## Internal Splinting

Pinning the bones together with Kirschner wires we term internal splinting. For arthrodesis of metacarpals and phalanges the wires, obliquely cut for neat drilling, cross and penetrate each fragment while the bones are held tightly together (see p. 45). To fail to do this would cause distraction. The wrist is similarly held in arthrodesis. Metacarpals after fracture, osteotomies, jogging, or reconstruction by bone grafts may be pinned longitudinally, transversely, and obliquely through each other and into the carpus or wrist, if necessary. Should the last procedure be required, exact immobilization by plaster cast is necessary until the wire is removed.

All pinning operations should fix the bones firmly and immovably together. Pins are clipped off beneath the skin to prevent infection, and are later removed under procaine hydrochloride with roentgenogram guidance. If wires are left protruding from fingers, they should be kept sterile and dry with dressings.

## Splinting for Fractures

Lack of traction is responsible for much of the malunion observed in the first 3 or 4 weeks after injury. Under these circumstances the metacarpals and phalanges show overlapping, angulation, and faulty rotation. The metacarpals buckle backward toward the dorsum of the hand and the proximal phalanges buckle volarward. Both positions disturb muscle balance from the point of angulation distally.

In the treatment of either metacarpal or phalangeal fractures a plaster cast on the hand and forearm furnishes a foundation for the metal extension used for traction (Fig. 14). The extension may be padded duralumin strip or a long loop of soft wire drawn straight, incorporated in the plaster at palm and wrist, padded, and extended beyond the flexed finger. It is curved, so that the proximal finger joints are in 45 degrees flexion and the interphalangeal joints are flexed still more. The finger lies along such a curved extension, which in turn is held in place by a cord extending from it to the belly of the splint to maintain the proper flexion. If there is no displacement, traction on the finger is by adhesive on the skin. Otherwise, pulp (Fig. 14) traction is occasionally, and skeletal rarely (Fig. 15), used from the finger to the extension apparatus. In either method a stiff piece of stainless steel wire or a fine Kirschner wire is used for traction. Each end of the wire is bent down the finger to terminate ½ inch beyond the fingertip as a ring or hook to which is attached the traction cord. Special traction bows or steel safety pins may be used.

If pulp traction is used, the wire which is pointed by clipping it obliquely, is thrust through the finger pulp from side to side. It should penetrate exactly at the spot marked in the diagram (Fig. 14 A) opposite the midportion of the nail, so that it will avoid the sheath of the flexor tendon, the phalanx, or the matrix of the nail. In skeletal traction (Fig. 15) Kirschner wire of a fine size is drilled laterally through the head of the proximal phalanx avoiding the joints and the lateral bands of the dorsal aponeurosis. This type of traction has the advantage of keeping the collateral ligaments of the proximal finger joints drawn out to their full length. Unless they are maintained at normal length by keeping the joints flexed, the joints will not be able to flex.

The various types of splints used during the war, both in the theaters of operations and the Zone of Interior are further explained and illustrated in other chapters. Many of them were ingeniously devised from materials at hand in the hospitals where they were needed. Some of them have been refined and are being employed in private practice today.[13]

[13] For more details on the principles of splinting, and extensive illustrations of hand splints, both past and present, reference is made to the *Orthopaedic Appliance Atlas*, published under the auspices of the American Academy of Orthopaedic Surgeons, in cooperation with the Office of The Surgeon General of the Army, and the Veterans Administration, by J. W. Edwards, Ann Arbor, Michigan, 1952.

## OCCUPATIONAL THERAPY AND REHABILITATION

### *Occupational Therapy*

Occupational therapy brings about real success in conditioning hands. It should be begun as soon as is consistent with the stage of healing and continued until discharge or reassignment. In addition to treating the injured part, it is important that the patient be treated as a whole, and that he be regarded, both physically and mentally, as a worker rather than an invalid. The activity selected should be of interest to him for he will then be spurred on by competition and by the joy of accomplishment with a creative object and interest.

Improvement concurrent with use is a natural response to voluntary activity. Contrary to the degeneration of disuse there is revivification of tissues on voluntary use and with the will to do. It is in this respect that occupational therapy is superior to passive physical therapy. Physical therapy is of value in the first 2 weeks after operative repair to start the patient on the road to voluntary activity. It is also essential in paralytic hands which cannot voluntarily be moved, as in this type of injury the patient is taught to move his injured hand passively by his other hand throughout the day.

Often a patient actually inhibits all movement of an injured hand. He has so dissociated the hand from the brain that at first he really cannot use it. This type of casualty is a good candidate for occupational therapy. In his response to and his interest in what he is doing, and in his desire to work, he will gradually begin to use his hand and then will find that he can use it more and more. Interest in the work causes him to activate the part all day instead of just for a single hour of treatment by physical therapy.

In the hand centers set up in World War II in the Zone of Interior it was found to be a sound principle to have patients use their injured parts to run machinery by which something could be made by sanding, boring, sawing, and similar activities. In their interest in doing the job they began to take their minds off their injured hands. In driving machinery by hand a graded brake was found helpful because it gradually increased the resistance. Also in the hand wards it was beneficial to have the patients do all of the work possible, such as sweeping, scrubbing, making beds, and waiting on other patients. Moreover, occupational therapy could be brought to the bedside of patients who were not ambulatory.

The following useful procedures for bringing about certain desired movements in crippled hands were gathered from the various general hospitals in which hand centers were located (Table 4):

TABLE 4. OCCUPATIONS DESIGNED FOR SPECIAL PURPOSES IN THE REHABILITATION OF CRIPPLED HANDS

| Occupations | Fingers | | | | Thumb | Wrist | | |
|---|---|---|---|---|---|---|---|---|
| | Flexion of proximal finger joints | Flexion of all joints | Extension of all joints | Flexion of proximal joints and extension of distal two joints for claw hand | Opposition of thumb | Dorsiflexion of wrist | Supination of wrist | General limbering up of hand |
| Carpentry: | | | | | | | | |
| Sanding with special blocks | X | X | X | X | X | X | ------ | X |
| Graded sizes of tool handles (files, chisels, screw drivers, hammers, saws) | X | X | ------ | X | ------ | ------ | ------ | X |
| Screw driving | ------ | ------ | ------ | ------ | X | ------ | X | X |
| Filing, chiseling, sanding, hammering, planing, spoke shaving | X | X | ------ | X | X | X | ------ | X |
| Clay modeling, potter's wheel | X | X | X | X | X | X | ------ | X |
| Printing, typesetting | ------ | X | ------ | ------ | X | ------ | X | X |
| Typing | ------ | X | X | X | ------ | ------ | ------ | X |
| Weaving (throwing shuttle, beating, braid weaving) | X | X | X | X | X | X | X | X |
| Cutting with scissors | X | ------ | ------ | X | X | ------ | ------ | X |
| Cutting linoleum blocks | X | ------ | ------ | X | X | ------ | ------ | X |
| Minor Crafts: | | | | | | | | |
| Basketry | X | X | X | X | X | X | X | X |
| Cord knotting | X | X | ------ | X | X | X | X | X |
| Leather tooling, lacing, punching | X | X | X | X | X | X | X | X |
| Radio construction | ------ | X | ------ | ------ | X | ------ | ------ | X |
| Finger painting | ------ | ------ | X | X | ------ | ------ | ------ | ------ |
| Gardening | X | X | ------ | X | X | X | X | X |
| Recreation sports | X | X | X | X | X | X | X | X |

*Flexion of Straight, Stiff Proximal Finger Joints.* This was the most universal need.

1. Sanding blocks (Fig. 16) were made to fit the hand so that when they were grasped and pressed on with the other hand the proximal finger joints were forced into flexion over the rounded fulcrum. This fulcrum was sometimes a rounded, gable-like angle; sometimes it was rolled over like the crest of a wave. There were round holes in which the fingers could be held flexed and a side hole in which the thumb was held in opposition.

2. Weaving with the shuttle held so that its edge acted as a support under the proximal finger joints.

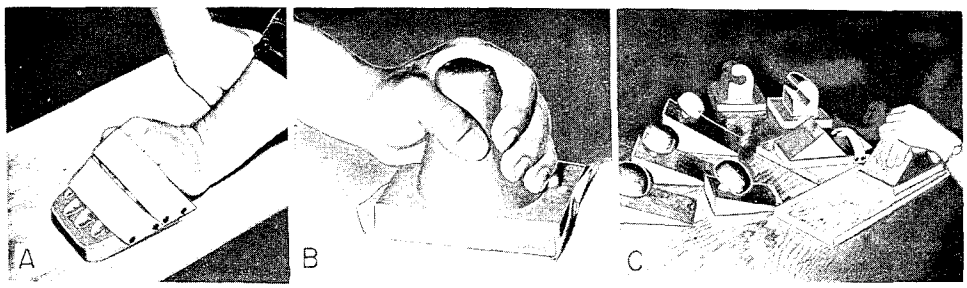



*Figure 16. Sanding blocks used in occupational and physical therapy. A. Blocks of various shapes used to flex joints of fingers and oppose thumb. Note position of hands. B. Sanding block used to flex metacarpophalangeal joints and extend the two distal joints of the fingers. C. Sanding block used to flex fingers and oppose thumb.*

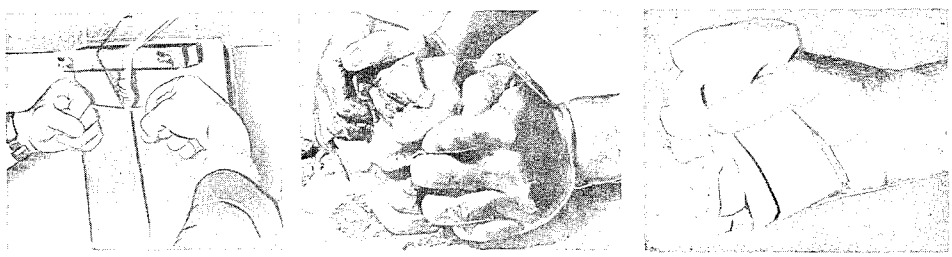


*Figure 17. (Left) Cord knotting used to increase flexion of fingers and opposition of thumb.*

*Figure 18. (Center) Kneading of clay until bubbles are out, to mobilize the whole hand; especially good for flexion of all finger joints.*

*Figure 19. (Right) Gripping sponge rubber to mobilize and flex the digits. This is good illustration of the usefulness of simple materials in accomplishing rehabilitation of an injured hand.*

3. Sets of files and other tools were used and were made with rounded or triangular handles, graded in size from ½ inch to 2½ inches in diameter.

4. Cord knotting (Fig. 17). The strings which had to be wound over small blocks of wood provided forced flexion of the proximal finger joints which held the blocks.

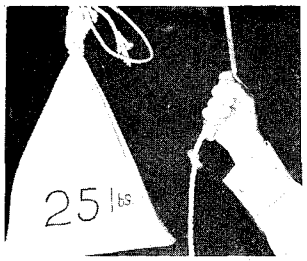
5. Material of graded thicknesses was cut with scissors.

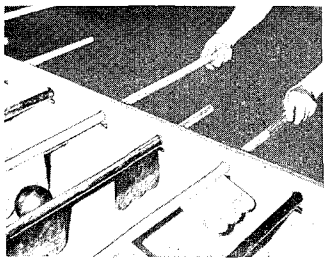
6. Clay was modeled (Fig. 18) and sponge rubber was gripped and manipulated (Fig. 19).

*Flexion of all Finger Joints.* The following methods were used to accomplish this result:

1. Flat rectangular blocks with rounded edges were carried in the pocket and used for gripping.

2. Tools with handles of various sizes were used.



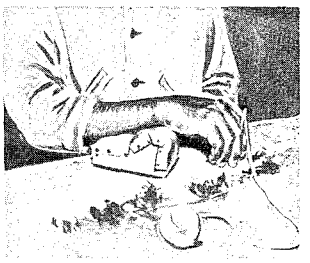


*Figure 20.* (*Left*) *Pulling on a rope to which a weight is attached to strengthen the grip and improve flexion of the digits.*

*Figure 21.* (*Center*) *Game with ball and paddles, used to increase pronation, supination, flexion of the fingers, and general mobility of the hand. This game can also be used to strengthen the grip.*

*Figure 22.* (*Right*) *Working with the wrist supported by a block, to improve wrist flexion. If improvement in extension is needed, the position of the block is reversed and the wrist held down by a strap.*

3. Clay was modeled (Fig. 18) and sponge rubber gripped and manipulated (Fig. 19).

4. Sanding blocks (Fig. 16) were used as already described.

5. Graded blocks were placed on the ends of hacksaws.

6. Machinery was run by gripping and turning axles.

7. Gripping was practiced with the hands in warm, soapy water.

8. A rubber ball was compressed and air was pumped until a record degree of pressure was obtained or until water was forced from one bottle to another.

9. The grip was strengthened and the fingers limbered by pulling on a rope to which a weight was attached (Fig. 20).

10. A game played with a ball and paddles (Fig. 21) increased pronation and supination and flexed the fingers as well.

*Extension of Fingers.* This result was achieved by the following activities:

1. Sanding with blocks of graded size and with rounded tops to force the fingers into extension (Fig. 16). The other hand was placed on top of the injured hand so that extension would be stronger and maximum (Fig. 16 A).

2. Paper cutting, holding the paper flat and firm for a hand-operated paper cutter.

3. Pattern making. In tracing patterns the fingers were strained in extension while the template was held down flat.

4. Clay modeling. Soft clay for making tiles was spread into pan-like molds.

5. Braid weaving. The fingers were held in extension while weaving was tacked down.

6. Finger painting, potter's wheel, and many minor crafts.

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*Flexion of Proximal Finger Joints and Simultaneous Extension of Distal Joints as in Correcting Claw Hand.* Flexion of the proximal finger joints and extension of the distal joints have already been discussed under appropriate headings. Each joint was treated separately. The two distal joints were strapped to a flat splint, in extension, while the proximal joints were being flexed. Finger painting, minor crafts, and radio reconstruction were also used to secure these objectives.

*Opposition of the Thumb.* This was frequently needed. It was accomplished by:

1. Sanding. The block had a hole in the side for insertion of the thumb to be forced into opposition.
2. Cutting of material of graded weight with scissors.
3. Pounding leather, graded by weight of leather.
4. Weaving. This activity included warping of the loom and picking up of the threads to be threaded through the needle. The warping hoop was used in threading the loom.
5. Typesetting, picking up and placing the type.
6. Screw driving.
7. Writing with a pencil built to fit the hand.
8. Braid weaving. The material used was wound in small balls to necessitate grasp between the thumb and fingers.
9. Use of small parts and tools as in radio reconstruction.
10. Minor crafts (see Table 4).

*Dorsiflexion (Flexion) of Wrist.* Activities for this purpose included:

1. Block printing, the block being inked while it was held at an angle.
2. Printing. The final push on a hand lever press gave maximum dorsiflexion of the wrist.
3. Sanding. The flat block was used and the wrist was held in dorsiflexion by placing the work on a low bench.
4. Cord knotting. Short strings were wound on small blocks of wood and pulled tight by dorsiflexing the wrist.
5. Weaving. This was done on a large loom. The beater was brought against the weaving while grasped with the wrist in the dorsiflexion position.
6. Spoke shaving.
7. Recreation sports and gardening.
8. Turning a small wheel with a handle while the forearm was braced on a block.
9. Working with the wrist supported over a block (Fig. 22).

*Supination.* This was accomplished by:

1. Turning the machinery for a jigsaw, filing, sanding, and similar activities by turning T-shaped handles in rotation.
2. Swinging in rotation heavy dumbbells or rods.
3. Using the printing press lever, palm up and palm down.

4. Turning a T-shaped handle with the axle placed between two boards screwed together for brake resistance.

5. Using a screwdriver. Screws with left hand threads were provided for the left hand.

6. Pulling a leather thong through holes.

7. Cord knotting (Fig. 17). The strings were pulled tight. Stabilization of the elbow prevented compensation by its movements.

8. Weaving. The weight of the shuttle and material was graded. This activity consisted of throwing the shuttle through the shed.

9. Gardening and recreational activities (Fig. 21).

*Limbering Up and Strengthening the Hand in General.* Carpentering involved many procedures providing a wide range of varied motions. Projects were selected to bring out the motions as desired. Weaving, clay modeling, gardening, recreational sports, and minor crafts were especially useful (Table 4).

## Reconditioning in a Special Hand Ward

Typical of the reconditioning of patients with injuries of the hand and wrist was that done in a special ward at Harmon General Hospital, Longview, Texas. All with injuries of this type who had reached the stage where some sort of exercise was desirable were placed in a single ward in close proximity to the physical and occupational therapy departments.

This ward was organized as a part of the orthopedic section, under the immediate supervision of the chief of the physical and occupational therapy departments. It was run entirely by the patients. All cleaning, bedmaking, and other work was done by them. No one who needed nursing care was transferred to it. The wardmaster was one of the detachment men who was an artist and experienced in the use of tools.

Specific programs were outlined to occupy the entire morning. The program consisted of games, exercises, clay modeling, drawing, painting, and other activities which required the patients to use their hands. Appointments for physical therapy were made in the afternoons.

The ward was decorated with posters advocating the use of the hands, with model airplanes, handmade ash trays, small hand looms, and similar objects. The ward solarium was equipped with a number of small work benches which had been made in the occupational therapy section. The open porch was given over to games such as dart-throwing, pinball machines, and similar activities which required the use of the hands.

The ward worked out very well. It was formerly most difficult to keep the patients active. They apparently felt inferior when they worked in the occupational therapy department when they had to compete with patients whose disabilities were other than those of the hand and the wrist. When the

special hand ward was set up, however, they seemed quite content. They had the responsibility of the operation of the ward, and entered into the various activities with enthusiasm. As a result, progress was notable.

The concept of a hand ward for reconditioning has the obvious advantage of relieving the routine monotony of treatment and accomplishing the reconditioning of patients with hand injuries in an interesting as well as an educational fashion. The men worked well as a group, took pride in their accomplishments, and conveyed to newcomers on the ward the idea that much could be done to improve disabilities of this type.

## Work Furlough

The most striking phenomenon of rehabilitation, and one which was commented upon by all surgeons who had an opportunity to observe it, was the marked improvement in hand function that always attended a prolonged furlough. At the expiration of a leave of 30, 60, or 90 days, patients almost invariably showed definite increase in useful activity of the hand. This was most apparent when work furloughs were granted and the patient was engaged in useful and gainful occupation, though it seemed to make little difference whether or not the work done was specifically designed to improve hand function. Even when no regular work was performed during the furlough, distinct improvement occurred. Undoubtedly the mere passage of time had something to do with this, but medical officers were repeatedly impressed with the fact that following furlough improvement was more pronounced than that achieved in comparable periods of time spent in physical and occupational therapy under hospital auspices.

## Rehabilitation in a Convalescent Hospital

Concepts of the value of exercise, physical, occupational, and recreational therapy were carried over from the general hospitals into the convalescent hospitals. These were equipped to carry on the various types of therapy which had been prescribed for individual patients to aid in the completion of their rehabilitation. A further incentive was added in the form of training or retraining in special skills directed toward preparation of patients for useful and gainful employment after discharge from the Army. In these courses of instruction special attention was given to the matter of rectifying or compensating for such handicaps.

Supplementing the directed and prescribed activities were the opportunities for free recreation amply provided at the convalescent hospitals. Such recreation played an extremely important part in the restoration of function to injured hands. The patient in enjoyable competition in such sports as golf, tennis, horseshoe-pitching, volley ball, soft ball, and swimming tended to forget

or ignore his disability and to gain unexpected usefulness and facility in the damaged member.

Encouraged by the improvement generally noted during the period of observation, it seemed safe in most cases to predict that additional improvement of disabled and rehabilitated hands would continue for some time after the patients' discharge from the Army. Since such improvement had been noted even up to a year following reconstructive surgery, final results of the treatment of these injured hands by Army surgeons were not truly to be evaluated at the time of the separation of the patients from the service. Ultimate results, it was believed, would in many instances be much better than had been foreseen.

# *HAND INJURIES IN THEATERS OF OPERATIONS*

CHAPTER III

# Hand Injuries in the Mediterranean (North African) Theater of Operations[1]

*Harvey S. Allen, M. D.**

## SURVEY OF HAND INJURIES IN THE MEDITERRANEAN THEATER OF OPERATIONS

In his first report made after assuming the position of Civilian Consultant for Hand Surgery to the Secretary of War, Dr. Sterling Bunnell commented adversely on the condition of many patients with hand injuries on their return from overseas to the Zone of Interior (see Chapter II). In general, these criticisms were accepted in the Mediterranean Theater of Operations as completely justified. For months preceding the issuance of the Civilian Consultant's report there had existed a spirit of pessimism in both base and forward areas relative to the results which were being secured in this type of injury. There was a variety of reasons for this feeling, among which the following were perhaps the most important:

1. So-called "lightly wounded" patients were appearing at medical installations in unexpectedly large numbers and their "minor" wounds were proving anything but easy to manage.

2. Few surgeons in the theater had had any experience in caring for wounds of the hands, or were particularly interested in them.

3. There was no overall policy of management for wounds of the hands such as there was for most other types of wounds. Many of the procedures, particularly the management of fractures, were unphysiologic and producing highly unsatisfactory results. Opinions differed widely on when to amputate and how soon motion should be permitted.

4. A large proportion of secondary closures of wounds of the hand were followed by poor results. Both early and late operations for tendon suture and other types of reconstructive surgery had been attempted but had proven equally unsatisfactory. Prevention of the stiff, doughy hand was a serious and still unsolved problem.

5. Reliance placed on physiotherapeutic measures to produce satisfactory end results had proved to be misplaced.

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*Associate Professor of Surgery, Northwestern University Medical School. Formerly Lt. Colonel, MC, AUS.

[1] The North African Theater of Operations was combined with the Mediterranean theater when the latter was established.

6. There was a high percentage of failure in the prediction of the type of duty which could be expected of soldiers with hand injuries after discharge from the hospital.

This was the situation when in February 1945 Lt. Col. Harvey S. Allen was ordered to make a tour of the Mediterranean theater to investigate the status of treatment of hand injuries and the problems of hand surgery and to report thereon to Col. Edward D. Churchill, Theater Surgical Consultant.[2] This tour, which lasted from 26 February to 17 April, included visits to all general hospitals and to most of the more active station hospitals in the base area; visits to all evacuation and field hospitals in the forward area under the supervision of the Surgeon, Fifth Army; an investigation of the records concerning hand injuries in the Surgeon's Office at Allied Force Headquarters,[3] and an analysis of the cases encountered on the hand service at the 12th General Hospital.

In the course of this tour, the surgeons interested in the problems of hand surgery were seen in conferences, and rounds were made on wards where patients with hand injuries were segregated. Operations were performed at several evacuation hospitals to demonstrate incisions used in correcting hand injuries. Other technical surgical procedures, including demonstrations of dressings and splinting, were also featured. Lt. Col. Howard E. Snyder, Fifth Army Surgical Consultant, supervised the visits to the various forward hospitals and arranged for talks to be given on hand surgery and for demonstrations of proper methods of application of pressure dressings and transportation splints.

## Report of Survey

In his report to the Theater Surgical Consultant at the conclusion of Colonel Allen's tour [4] he remarked that the care of wounds of the hand was frequently relegated to younger surgeons both in forward areas where debridement was performed, and in base hospitals where reparative surgery was undertaken. There was a tendency to assign the larger wounds to more experienced surgeons. Since the size of the wound often had little to do with its seriousness, such an assignment was illogical, as many large wounds in spite of their size were not as crippling as smaller ones, and not so difficult to handle. The policy employed did not take into consideration the many movable and vital structures including bones, nerves, and tendons, which small as well as large wounds of the hands might involve.

It was often impossible because of the seriousness of the injuries to handle all the necessary surgery at a single hospital, particularly if inexperienced men

[2] Allen, H. S.: A review of surgery of the hand in MTOUSA. HD: 730 (Hand Surgery) MTO.

[3] The paucity of reports on surgery of the hand, in comparison with the amount of material available on almost all other military injuries, made it impossible subsequently to incorporate many data from this source in the report to the Theater Surgical Consultant.

[4] See footnote 2 above.

were in charge. As a result there was a staging of treatment, with attendant delay, as the patient was passed from one installation to another until he reached a surgeon experienced enough in hand surgery to undertake his care.

Patients with hand injuries who arrived at base hospitals after treatment in forward area hospitals illustrated the lack of a definite policy for handling these injuries. Not all wounds were splinted, particularly if only soft tissues were involved. Occasionally the patient held his injured hand, covered only with a thin, blood-stained bandage, against his chest to protect it from further trauma. Some patients arrived with rings and identification bracelets still in situ on the injured extremity. Splints and casts were of all sizes, shapes, and kinds. Surgeons in the theater fluctuated between overzealous splinting maintained for too long periods and the equally impractical, harmful policy of not splinting any wound or fracture of the hand.

Among the many problems encountered at the base hospitals the following were selected for citation:

### Secondary Closure

The plan of secondary closure of wounds, which in general had given excellent results, was not uniformly successful in wounds of the hand. At the 64th General Hospital for example, over half of all failures of secondary closure done on the orthopedic service involved hand wounds. Most surgeons at other hospitals shared the opinion that closure of these wounds was frequently unsuccessful and disappointing either because of breakdown or infection.

Reparative surgery should be done at the optimal time, early, and should be complete. Too often either the palmar or dorsal wound was closed, the hand placed in a cast, and the remaining wound ignored, at least temporarily. Sometimes patients were returned to the operating room after an interval of a few days and further closure attempted (Fig. 23). It was often possible to close the soft parts easily if one ignored fractures but this was not good surgical judgment. It was also true in these cases that there was the greatest difficulty in obtaining closure. The skin might be closed but a neglected fracture would be left in malposition. Closure of the soft parts had to be done in a manner consistent with the proper position of a fracture and preservation of the function of the underlying damaged tissue.

Failure to get the same good results in hands as elsewhere on the body from reparative surgery was attributed to a variety of factors peculiar to the hand. These were:

*Amount of Skin Debrided.* Each wound demanded some excision of skin edges but it should have been minimal. All viable skin and subcutaneous tissue should have been saved regardless of shape or appearance of the wound. Any loss of skin made reparative and reconstructive surgery more difficult. Since there is no excess tissue on the hand, mobilization of skin at time of

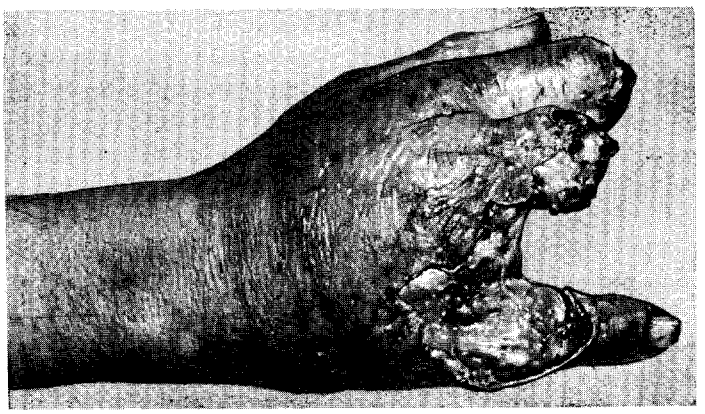


*Figure 23. Grenade injury of right hand, with amputation of index, middle, and ring fingers and loss of skin over dorsum of little finger. Appearance of hand after 4 weeks of treatment. The result is typical of cases treated without a definite plan of attack. The wound is still open and nothing has been accomplished by the use of a plaster cast.*

closure is difficult or impossible. In order to get a closure the surgeon was tempted to apply excessive tension on the wound edges. Sutures, under these conditions, sloughed out leaving a moist, broad wound and, eventually, greater scarring. Better results followed in such cases when free grafts or skin flaps were used, but even these procedures would not compensate for wide skin loss (Fig. 24). Skin and subcutaneous tissue must either be saved early or replaced later by tedious operations.

*Post-Traumatic Swelling.* Post-traumatic edema was present almost uniformly on the patient's arrival at the base hospital. The hand swells to great proportions after injury coupled with surgery, and when to this is added a few days of hanging in a dependent position in a low sling, edema becomes excessive. Crushing types of wounds are notorious for producing swelling, and the pres-

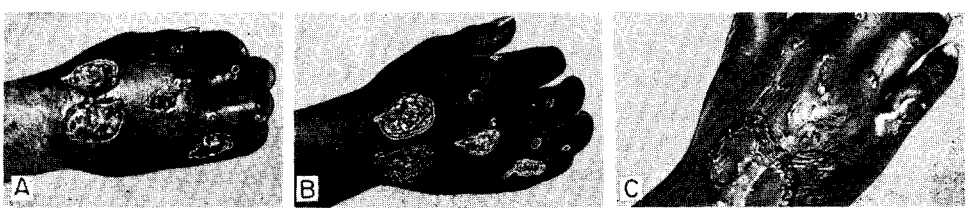



*Figure 24. Small penetrating shell-fragment wounds of dorsum of right hand. A. Appearance of hand 4 days after unnecessarily extensive debridement. B. Suture of small wounds and skin replacement of widely excised wound. Because of the unnecessarily radical debridement, no other method of closure was possible in this case. C. Healed wounds 6 days after secondary closure by skin dressing.*

ence of deep, tight packing, continued hemorrhage and persistent motion of the injured part all contributed to it.

The edges of a modest wound of either the palm or the dorsum could not be approximated easily in a tense, swollen hand although there may have been only a minimal loss of skin from injury and debridement. Swelling produced a nonreducible gaping of the wound. Sutures under tension in the presence of the swelling led to wound breakdown and delay in healing.

Post-traumatic swelling was more easily prevented than cured, for once established it was most difficult to reduce. Persisting edema led to ultimate fibrosis and stiffness. The swollen hand with the puffed dorsal surface, obliteration of the palmar concavity, and thickened digits, splinted and fixed the joints and intrinsic muscles and impaired the ultimate function.

Swelling might be limited and kept at a minimum by early attention to such small details as reasonable alinement of fractures over an adequate splint, an efficient pressure dressing, and constant elevation of the part.

*Flaps of Skin and Subcutaneous Tissue.* The perforating, "bursting" type of injury produced irregular flaps of skin and subcutaneous tissue on the dorsum of the hand. At the time of closure these flaps were often a real problem for they were retracted, edematous, macerated, and curled under so that the skin was constantly bathed in wound secretion. Their vitality was so lowered that they frequently did not tolerate sutures and required excision back to healthier tissue (Fig. 25). This excision increased the size of the defect and made closure more difficult. A flap with its base attached distally had a bluish discoloration from interference with its venous return. When a curled under, retracted flap was used it frequently became gangrenous, as the following case shows:




*Figure 25. Perforating wound of left hand, with compound fracture of proximal phalanx of third finger. A. Appearance of wound 5 days after injury and debridement, showing markedly edematous, curled-up skin edges of dorsal wound. B. Typical small wound of palmar surface of hand. C. Roentgenograms showing poor alinement of fracture in occlusive boxing glove type of plaster splint, which invariably accentuated edema and maceration and failed to hold fractures in alinement.*

*Case 1.* On inspection of the hand in the operating room the fifth day after injury, a defect on the dorsum of the left first web space was found extending from the web to the wrist, measuring 2½ by 2 inches. The extensor tendon to the index finger and the capsule of the wrist joint were exposed. Actually

there was no skin loss, but the flap of skin and subcutaneous tissue was completely curled upon itself at the level of the wrist. The skin was macerated, pale, and thick, but accurately fitted the defect. Two sutures only were inserted to hold the skin in place and a pressure dressing and splint were applied. By the seventh day the distal two-thirds of the flap was gangrenous and was removed. Final closure was obtained by a split graft but the extensor tendon was firmly embedded in the scar and the thumb was held in an adducted position.

Salvage of these flaps for delayed closure might have been accomplished by restoration of the flap to a normal position following debridement. A flap might be held in position by one or two sutures or by the pressure dressing itself. Splinting was important to prevent motion from causing the edges to roll under.

*Skin Macerations.* The wounded hand tended to macerate easily and the presence of moisture was often a reason for failure to obtain healing by secondary closure. Maceration was aggravated by the use of vaseline gauze as a dressing (Fig. 26). Interdigital maceration occurred unless gauze was inserted between the fingers.




*Figure 26. Lacerated wound of palmar aspect of right hand, across web space, involving all digits. A. Appearance of wound just before secondary closure. Note excessive maceration resulting from use of vaseline gauze. B. Appearance of hand after cleansing and removal of sutures placed at initial operation. The edges of the wound are soft and friable, and satisfactory secondary closure will be difficult to achieve. C. Healed wound 8 days after secondary closure. In the interim following operation the hand has been on a dorsal splint, which provided relaxation and rest.*

### Compound Fractures

Another troublesome problem confronting the surgeon at the base hospital was that of treatment of compound fractures of the bones of the hand. These cases again revealed the lack of a definite policy. Methods varied from simple dressings to skeletal traction. The variety of splints and casts used was remarkable. In some instances a simple incomplete fracture might be excellently splinted while the next casualty might reveal multiple compound comminuted fractures splinted only by tongue depressors. The most important errors observed were:

*Position of Fractures.* Insufficient attention was paid to the position of fractures when the dressing and cast were applied following debridement, with

the result that the fractured bone and corresponding digits were often left in distorted positions (Figs. 27, 28, and 29). This could easily have been avoided. Accurate, time-consuming reduction of fractures was naturally not expected in forward hospitals, but if the bone ends had been more carefully alined by simple manipulation of the digits over a molded splint, the fracture could have been held in alinement by a pressure dressing, and hemorrhage, edema, and dead spaces would have been less of a subsequent problem.

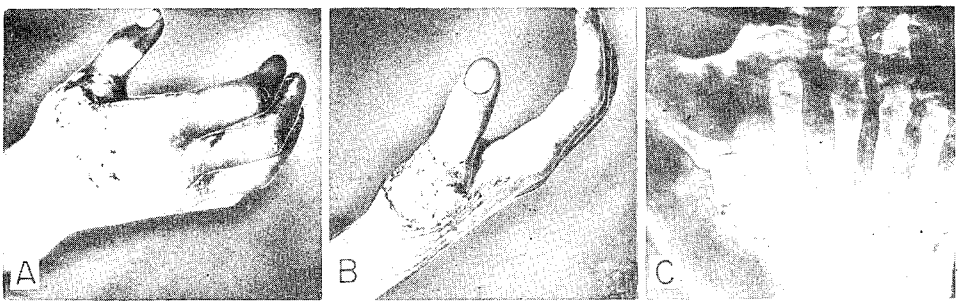



*Figure 27. Compound fracture of first metacarpal of right hand. A and B. Healed soft tissue wound following closure. C. Roentgenogram of hand showing that alinement of fractured bones was ignored when soft tissue wounds were closed.*

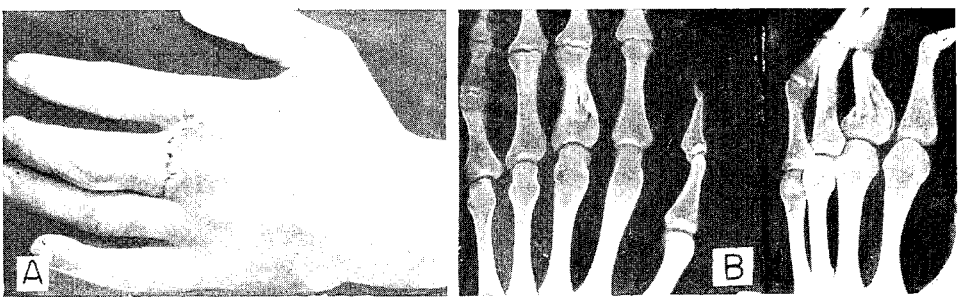



*Figure 28. Compound fracture of proximal phalanx of left middle finger. A. Photograph showing clinical evidence of poor alinement of fracture. B. Roentgenograms confirming clinical evidence of poor alinement of fracture. This case, like the preceding (Fig. 27), illustrates the poor results obtained when attention was devoted only to the soft tissue phase of injury and when perfect alinement of osseous tissue was not considered an integral phase of the repair. Whenever the various steps of management of hand injuries were dissociated, it was unlikely that a satisfactorily functioning hand would be obtained.*

*Reduction.* Accurate reduction of fractures (Fig. 30) which was the basic principle of reparative surgery as it concerned bone, was sometimes neglected and all attention concentrated on skin closure. This was a serious error, since even a slight bony deformity near a joint or in a phalanx could impair the

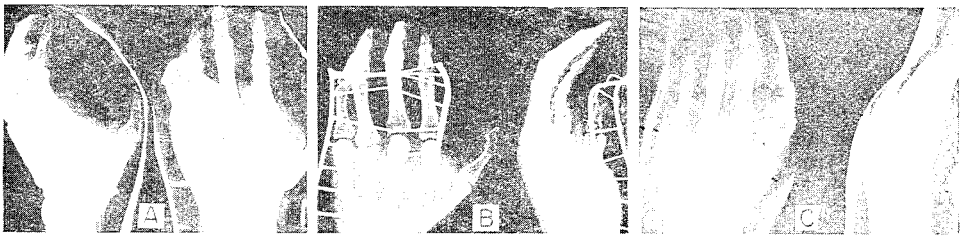


*Figure 29. Roentgenograms showing improper management of fractures following debridement of wounds of the hand. A. Roentgenograms showing severe compound fracture of left fourth finger, with very poor alinement of fragments in plaster cast. B. Roentgenograms showing fracture of metacarpal of left fourth finger, with overriding and poor alinement. C. Roentgenograms showing fractures of third, fourth, and fifth metacarpals, with bone loss, angulation of fracture, and hyperextension of metacarpophalangeal joints. In each of these injuries post-traumatic edema was marked, healing was delayed, and loss of function was serious.*

smooth gliding of tendons and seriously limit motion. This neglect of accurate fracture reduction undoubtedly accounted, in part, for the criticism of Dr. Sterling Bunnell, Civilian Consultant in Hand Surgery in the Zone of Interior to the effect that patients were being returned from overseas with overlapping, rotation, and shortening of fractured bones. Neglect of the fracture when closure was done, which ignored the role of the bony framework in the functioning efficiency of the hand, was frequently combined with the erroneous practice of instituting immediate early motion. Typical of this combination of errors were the cases in which shortening of fractured metacarpal bones had resulted in V-shaped deformities.

*Excision of Fragments.* A tendency was observed in the forward area to excise comminuted fragments of the metacarpal and metacarpophalangeal bones, with resulting loss of bone length. In one such case roentgenograms revealed a smooth defect of ¾ inch between the bone ends; the comminuted portions had been removed with bone forceps. It was always far better at

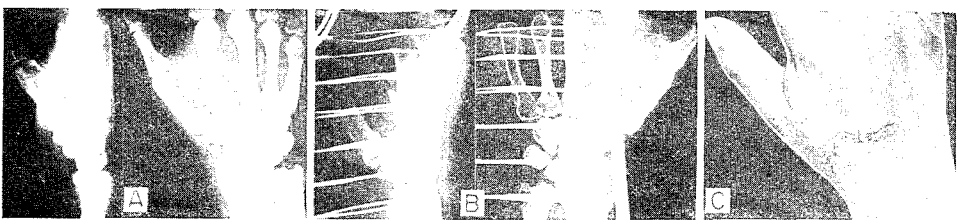


*Figure 30. Penetrating wound of dorsum of right hand, with compound fracture of second metacarpal. A. Roentgenograms taken in evacuation hospital. B. Roentgenograms of hand on transportation splint. C. Appearance of hand at initial dressing 6 days after operation. Motion was not instituted until clinical union of the fracture had occurred.*

the time of debridement to conserve all attached viable bone fragments, though badly comminuted, than to remove them and rely for their replacement on the sometimes dubious results of later bone grafting procedures.

*Splinting.* In numerous instances splinting incorrectly applied was observed. The chief error was a total disregard of the position of function (Figs. 31 and 32). In some cases unusually extensive local hemorrhage and edema could be explained by instructions previously given to patients to keep injured parts in constant motion in order to prevent stiffness. In other cases splints were kept in situ for an unduly long time.

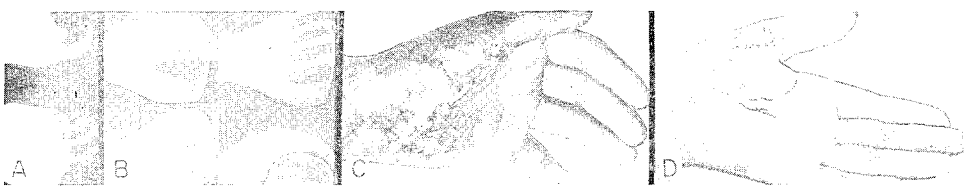



*Figure 31. Fracture of metacarpal of left thumb. A. Roentgenograms showing poor position of fracture in transportation splint. B. Roentgenograms showing hand on universal splint after manipulation and reduction of fracture. Note position of function in lateral view. C. Appearance of hand at first postoperative dressing. D. Appearance of hand 1 week later.*

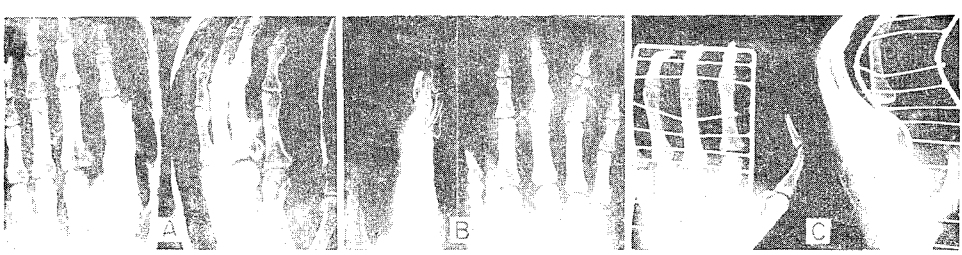



*Figure 32. Three instances of improper splinting. A. Roentgenograms of hand in boxing glove type of splint, with metacarpophalangeal joints in extension. B. Roentgenograms of hand splinted on straight board, with extension hyperextension at metacarpophalangeal joint and poor alinement of fracture of all small joints. C. Roentgenograms of hand on wire ladder splint, showing of third metacarpal. In all cases shown, the position of function has been completely ignored and poor results seem inevitable.*

*Swelling.* Insufficient attention was paid to the prevention of swelling and to the elimination of swelling when it had occurred, although neglected swelling served for all practical purposes as an internal splint which bound and fixed the smaller joints.

*Traction.* Traction was not always wisely used. It became increasingly unpopular as the war progressed, though in the early months of fighting it had enjoyed some degree of favor. Hands had sometimes been put up in

straight extension, traction through the pulp of the finger had been used improperly, and the tendency was to employ it for too long a period. Internal fixation also was seldom employed.

*Management.* From a functional standpoint the results of the management of compound fractures and even of simple fractures were often extremely disappointing. Closure of the wound was usually accomplished and sinuses to the bone were not frequent, but in a large proportion of cases the function of the healed part was unsatisfactory. In one sample of 65 such injuries at the 64th General Hospital,[5] only 1 patient had to be evacuated because of persistent drainage from the bone, but in numerous other cases edema, maceration of the skin, and loss of tissue at debridement, as well as at the time of original injury, made the functional results very unsatisfactory. At the 45th General Hospital,[6] almost 50 percent of the casualties observed with fractures of the metacarpal and metacarpophalangeal bones had to be evacuated to the Zone of the Interior because of residual dysfunction. This high rate was not the exception. It was regrettably typical of the end results of compound fractures in the Mediterranean Theater of Operations.

### Immobilization

Immobilization of the injured hand constituted an important phase of management after debridement in a forward hospital. By this means the hand was put at rest, and protected during transportation to the rear; further hemorrhage was prevented and post-traumatic edema minimized. Elevation of the hand during this period, as well as immediately after reparative surgery was also extremely important. No patient with a hand injury was properly treated unless he had been instructed to keep the extremity elevated, and unless those supervising his care saw to it that he followed instructions.

The Civilian Consultant in Hand Surgery in the Zone of Interior pointed out in his first report that the numerous poor results obtained in the care of hand injuries could be explained by the type of splinting employed overseas and by the unnecessarily long periods of time over which small joints were immobilized. Observations made during Colonel Allen's survey of hand injuries in the Mediterranean Theater of Operations early in 1945 frequently justified these criticisms (Fig. 32). At the time this survey was made, splinting of the hand by means of a simple straight board was seldom seen though it had been unfortunately common earlier in the war. Plaster molds, which were being used extensively, had not proved satisfactory. They were either so light that they broke at the wrist or so heavy and clumsy that the position of function was lost and the hand ended in a straight position. The plaster

[5] Cahen, I.: Experience in the reparative surgery of 500 consecutive compound fractures. M. Bull., MTO 3: 241–245, Jun 1945. HD.

[6] Duncan, G. A.: Review of orthopedic service of 45th General Hospital, 1944. Cited in Allen, see footnote 2, p. 80.

boxing glove splint, or its modifications, which had been widely used in the latter part of 1944, was now generally unpopular. This was for the principal reason that it did not produce the constant pressure supposed to be one of its advantages. Fractures put up in it were usually poorly alined, but the hand was usually swollen and greatly macerated. When patients were received with hands in this type of splint, it was currently routine practice at many base hospitals to substitute another type before anything else was done. The volar wire lattice type of splint was proving more satisfactory, but unless it was repeatedly inspected the hand would assume an incorrect position in it and hyperextension of the metacarpophalangeal joints would result (Fig. 32 C).

Pressure dressings, an integral part of successful immobilization, were seldom used to proper advantage. Most surgeons spoke intimately of the use of pressure dressings, but inspection of the wounds which they had dressed raised doubt whether they understood the purpose underlying their use or had learned how to apply them properly (Fig. 33). Pressure dressings were useful not only in keeping fractures in alinement after reduction but also in putting soft tissues at rest. It was frequently forgotten that a wound of the skin or muscles is in effect a fracture of the tissues, with loss of structural continuity.

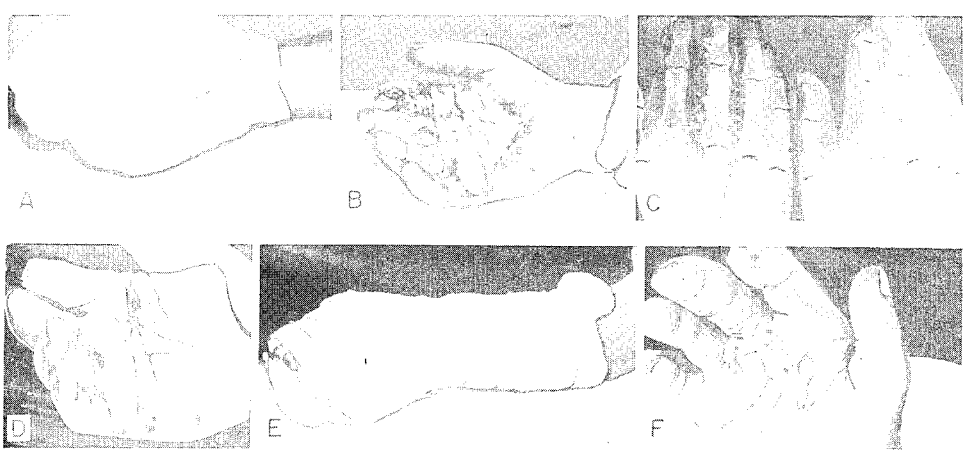



*Figure 33. Grenade injury of right hand with multiple wounds of soft parts and amputation of tip of index finger. A. Hand in loose occlusive dressing, without splinting. B. Appearance of hand just before secondary closure. Note marked maceration. C. Roentgenograms showing traumatic amputation of tip of right index finger and multiple small foreign bodies in situ. D. Appearance of hand at completion of operative procedure, with skin graft applied to amputated index finger. E. Hand put up in splint with pressure dressing correctly applied to provide rest for injured tissues. Compare this dressing with the dressing shown in A. F. Appearance of hand 21 days after injury. In this case failure to immobilize the hand immediately after injury and the faulty method of bandaging, with the extensive maceration which ensued, made secondary closure unnecessarily difficult.*

Poor position resulted when fractures were put up with little regard to their alinement. When joints were splinted in extension, impaired function inevitably followed. When the injury involved the tendons or the small muscles that move the joints, or the joints themselves, the resulting scar tissue invariably immobilized the joint completely or greatly affected its ultimate motion. The end results were also seriously influenced by permitting the hand to become swollen and tense after injury, or after debridement or reparative surgery, or as the result of early postinjury or postoperative motion without a splint. The swelling and resulting induration permitted the collagen fibers to bind and freeze the capsules of the small joints and encouraged the establishment of a fibrosis which it was extremely difficult to overcome. Continued induration resulted in internal fixation which prevented free motion and otherwise limited the use of the hand just as effectively as did continued incorrect splinting.

### *Repair of Nerves and Tendons*

It was rather generally realized that reconstructive surgery was not the type of surgery to be performed in an overseas theater. In the few instances in which repair of nerves and tendons was undertaken at the time of secondary closure of the wound, results were almost uniformly disappointing. In an extreme instance of poor judgment studied during the survey it had been possible to approximate the ends of the divided flexor and extensor tendons only by ignoring the fractured metacarpals. The ultimate result in this case was overlapping of the fractures, a wound which did not heal kindly, the firm inclusion of the sutured tendons in the scar, and a thickened, swollen hand.

### *Amputations*

In early 1945 the indications for amputation of one or more digits were in a state of considerable confusion in both forward and rear areas. Numerous questions were propounded in the course of Colonel Allen's investigation: What should be done for disruption of the metacarpophalangeal joints—should the entire digit be removed? What should be done for severe shattering of interphalangeal joints? Was it worth while to attempt to save a digit or a part of the hand if a long period of hospitalization would be required before the patient could be returned to limited duty? If amputation were decided upon, should it be done through the site of the fracture, or through healthy bone, or at the proximal joint?

Many of these questions might have been answered by the surgeons if they had visualized the final end results. It was always worth while to save a finger or any part of the hand (Fig. 34). Early amputation sometimes saved time, but only at the expense of the patient's ultimate efficiency. The decision to amputate always had to be a considered one, with the surgeon convinced when he advised it, that salvage of the parts was impossible. Since a single stiff joint

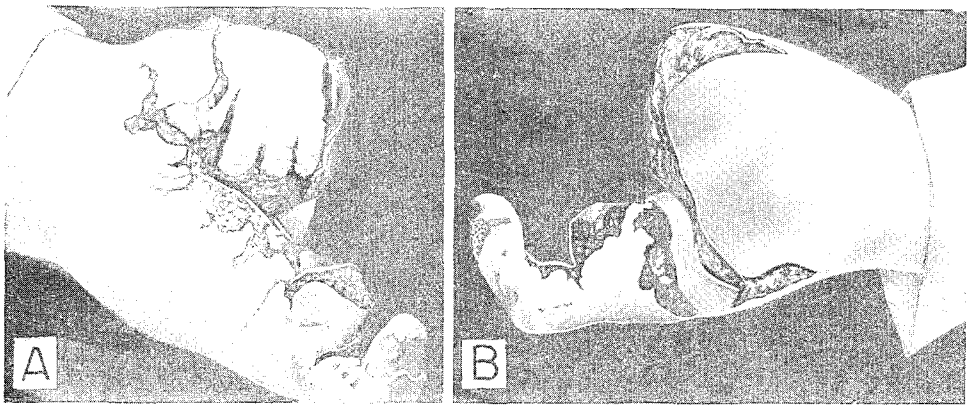



*Figure 34. Typical severe shell fragment injury of left hand. A and B. Palmar and dorsal views. On first inspection it sometimes seemed simpler to amputate a hand with injuries as extensive as these, but it was far more satisfactory to conserve whatever tissue remained. In this instance, although it required time and patience on the part of both surgeon and casualty, it was possible to leave the patient with normal sensation and motion in the remaining fifth digit.*

in good position is not in itself a serious handicap, amputation for damage of a single joint was never justified.

Badly shattered or mangled digits, or even whole hands, had to be removed, but even in the most severe cases it was often possible to save some part such as a metacarpal or part of a metacarpal which made the stump more valuable to the patient than if the hand had been amputated at the wrist. Amputation was commonly indicated for severely shattered and avascular digits, but routine amputation for all fingers exhibiting such wounds was not. The decision always had to be an individual one and even when amputation of a finger was necessary it was frequently possible to salvage some structure which could be made useful in the eventual function of the part.

In war surgery of the hand one rule had to prevail for the level at which amputation was done: All available viable tissue, regardless of shape or cosmetic appearance, was to be saved. The amputation of even small amounts of viable structure to facilitate closure was never indicated, particularly when the thumb was concerned. Without a thumb, or a stump which can serve as a thumb, the hand is of little value for the fingers must have something to oppose in order to be efficient in picking up or grasping objects. Moreover, a half- or a quarter-inch in thumb length can make a great deal of difference in function.

Although these principles of amputation must have been well known to all surgeons they were not always followed, as was evident from a number of cases observed in the course of the Allen survey. The mistaken idea prevailed early in the war that amputation in forward areas might be justified as a quick solu-

tion of difficult problems because the healing of small wounds was sometimes slow, and because the need for manpower was urgent. However, unless the surgeon was thoroughly convinced that function of the part was irrevocably lost and could never be restored, there was no justification for amputation. If there was any element of doubt the proper policy was to conserve all the viable tissue of the part, including the bone, with the assurance that if amputation proved necessary it could be performed at the base hospital. This plan did not conflict with the Army's need for conserving manpower. Only a few patients who had suffered amputation of even a single finger could ever return to full combat duty; almost without exception these men had to be placed in the limited duty category. Early amputation therefore furnished no assurance that the injured man could be restored to full combat duty.

As the result of unwise operations, many patients were left greatly handicapped, some because of unnecessarily shortened thumbs, others for a variety of reasons, as the following five cases show:

*Case 2.* A traumatic amputation of the thumb obliquely across the proximal phalanx had occurred, leaving attached fully viable skin extending distally to the tip along the dorsal surface. In order to permit the skin flap to "fall over and cover the resulting defect," the remaining portion of the proximal phalanx, measuring about ¾ inch, had been removed. The skin flap covered the defect, it is true, but at the expense of the function of the thumb.

*Case 3.* In this case, observed at a base hospital, a severe shattering injury of the interphalangeal joint of the thumb had resulted from a penetrating shell fragment. The note attached to the chart stated that the skin of the distal phalanx had been viable but that in order to achieve a "plastic" closure the thumb was amputated at the level of the midportion of the proximal phalanx (Fig. 35).

*Case 4.* This patient received a perforating wound of the left hand from enemy bullets, resulting in almost complete amputation of the left third digit. Shortly after wounding, amputation of the digit was completed at an evacuation hospital and the head of the third metacarpal was removed. Thirteen days later the wound was closed by secondary suture and skin graft. Healing was satisfactory but the patient had a marked deformity of the hand and considerable loss of motion of the thumb and index finger in all directions. The fingers were fixed in abduction, which increased the deformity.

*Case 5.* This patient sustained an accidental, self-inflicted gunshot wound of the right thigh and a traumatic amputation of the right middle finger. After debridement of the thigh wound had been carried out at an evacuation hospital, amputation of the wounded finger was completed and the remaining portion of the third metacarpal was removed. When the patient was seen at a general hospital his wounds were well healed, but the scarring following the amputation of the finger and of the distal third of the metacarpal made the function of the hand only about 25 percent of normal.

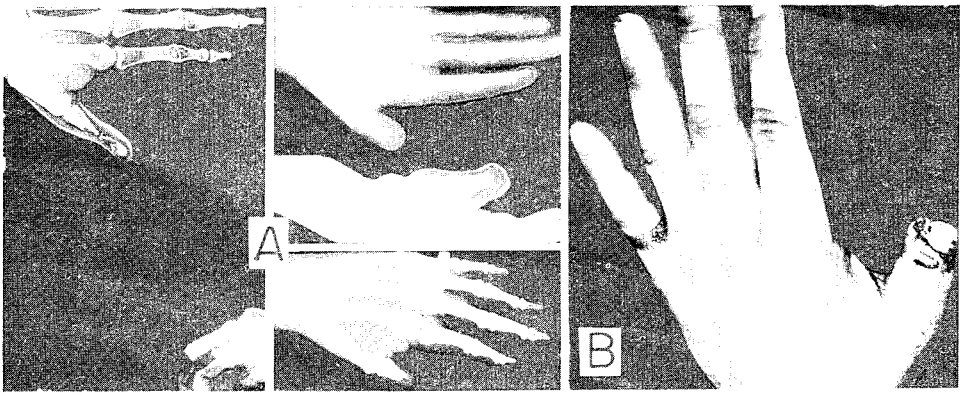



*Figure 35. Crippling result of unnecessary sacrifice of tissue of thumb. A. Roentgenograms of hand immediately after injury, showing soft tissue and portion of distal phalanx of thumb still in situ and susceptible of salvage. B. Appearance of hand at base hospital, showing unnecessary waste of vital soft parts and osseous tissue.*

*Case 6.* This patient arrived at a station hospital with an amputation of the hand at the wrist but with viable skin flaps 2 inches long on both the dorsal and volar surfaces. With that much viable skin remaining it seemed entirely possible that some portion, if not a considerable part, of even one metacarpal might have been saved. On arrival at the base hospital the wound could have been closed by a pedicle or free graft and the patient would have been left with a useful stump, in contrast to the useless one which was the result of too radical amputation.

### Classification

The classification of casualties with hand injuries was highly unsatisfactory. At the time of the survey, hospitals which rendered medical care for replacement depots and convalescent centers were obliged to tolerate a constant flow of patients with hand injuries who were admitted and re-admitted on complaint of painful scars, tender amputation stumps, nerve and tendon damage, stiffened digits with impaired function, and sometimes a true anxiety state in which the hand was a somatic factor.

## Recommendations

At the conclusion of the survey, the following recommendations were made to the Theater Surgical Consultant:

1. All surgeons in the theater should be given a better understanding of the importance of hand surgery, and the care of hand injuries and also taught to consider the hand as a functioning unit. They must fully understand the possible effect of the initial wound on movement and other functions.

2. The policy of the theater in respect to hand surgery must become more vigorous. Closure of open wounds must be hastened.

3. In forward areas the management of wounds of the hand should be under the supervision of a surgeon who understands the principles of debridement, methods of splinting, and the general care of such injuries. In base hospitals best results would be obtained if patients with hand injuries were placed on a separate hand service.

4. Splints should be applied which hold the hand in the position of function at all times. Such splints should be employed whether or not fractures are part of the injury and should be supplemented by a properly applied pressure dressing.

5. Surgeons managing casualties with hand injuries should estimate the probable disposition of each patient as soon as possible after he is seen. Much time and effort would be saved and many hospital beds conserved if patients were placed promptly in their proper categories. Many men undergo long periods of hospitalization, are then assigned limited duties, then pass to replacement depots, only to be reclassified in the end for evacuation to the Zone of Interior.

The report concluded with the statement that at that time, although the management of wounds of the hand left much to be desired, the appraisal of end results was not entirely fair. Some injuries were so essentially serious that minimum function was the best that could be hoped for. Conversely, poor results could not be blindly accepted when it was well understood that the hand is a single functioning unit and that even so-called minor injuries might cause extremely serious disability.

## GENERAL CONSIDERATIONS

### Incidence

No accurate statements can be made about the incidence of injuries of the hand in the North African-Mediterranean Theater of Operations, chiefly because of the lack of a consistent policy in their registration. In some hospitals fractures of the hand were treated on the orthopedic service, while soft tissue injuries, infections, and burns were handled on the general surgical services. In other hospitals all hand injuries were segregated into special wards. Often these injuries were associated with those of other parts of the body which were more severe and which, therefore, determined the registration of the patients. Head, abdominal, and chest injuries necessarily took precedence over hand injuries, and often the latter did not appear on the hospital census at all.

#### *Battle Areas*

Certain statistics, however, may be cited to give some idea of the frequency of hand injuries and of the distribution of the various types.

The incidence of hand injuries in forward areas naturally varied with the rise and fall of combat activities. At the 171st Evacuation Hospital, during the early part of the drive for Massa, Italy, 6–9 April 1945, 33 (14.7 percent) of 225 consecutive admissions for combat-incurred wounds consisted of hand injuries. Not all of these injuries were severe, it is true, but the hand was involved in some way in approximately 14 to 15 out of every 100 wounded men who passed through an evacuation hospital during a period of combat activity.[7] This incidence approximates that reported by Stewart and Ristine [8] who found that wounds of the hand and forearm represented 14.7 percent of all air-combat wounds. It also corresponds in general with the statistics collected by the 2d Auxiliary Surgical Group, where in a series of 455 operated wounds of the abdomen and chest, it was reported that 14.7 percent of the patients had injuries of the forearm and 10.5 percent showed injuries of the hand. These incidences are not very dissimilar from the 12.8 percent reported by Cole and Neel [9] for injuries of the hand in a series of injuries of the extremity sustained in amphibious warfare.

### *Base Areas*

At the 6th General Hospital, the 417 wounds of the hand observed during the 6-month period ending 31 December 1944 represented 5.1 percent of all hospital admissions and 8.3 percent of all admissions for battle and nonbattle injuries and wounds. The 320 patients in which an injury of the hand was the determining cause for hospitalization accounted for 3.9 percent of the total hospital admissions and for 6.4 percent of all admissions for battle and nonbattle injuries and wounds. The remaining 97 patients had additional injuries.[10]

Figures reported from the 12th General Hospital for the last 9 months of its operation show that hand injuries alone accounted for 8.2 percent of all admissions to the surgical service. The rate of admissions varied from month to month, ranging from 3.9 to 13.2 percent depending upon the character and type of the land operations and the local concentration of troops. The 901 hand injuries, when distributed according to type of wound, treated during the period in question, represented 22.7 percent of all accidental open wounds; 5.4 percent of all battle-incurred open wounds; 28.1 percent of all accidental compound fractures; 10.9 percent of all battle-incurred compound fractures; 6.7 percent of all accidental simple fractures; and 7.4 percent of all battle-incurred simple fractures.[11]

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[7] Allen, H. S.: Surgery of the hand in an overseas theater. HD: 730 (Hand Surgery) MTO.

[8] Stewart, J. D., and Ristine, C. R.: Distribution of air combat wounds. See also footnote 7 above.

[9] Cole, J. P., and Neel, H. B.: Injuries of the extremities in amphibious warfare. Surg., Gynec. & Obst. 79: 573–583, Dec 1944.

[10] Ltr, Lt Col M. K. Bartlett, MC, Surg Serv, to CO 6th Gen Hosp, 10 Mar 45, sub: Wounds and injuries of the hand. HD: 730 (Hand Surgery) MTO.

[11] See footnote 7 above.

Wounds of the soft parts formed an important proportion of hand injuries. At the 12th General Hospital during the last 9 months of its operation, 748 open wounds of the hand were treated, either alone or in combination with other injuries. Of these, 501 involved only the soft tissue and 247 were compound fractures. At that hospital during the same period the 306 patients seen with fractures of the hand, both accidental and battle casualty, represented 11.3 percent of the total number of 2,704 patients with fractures treated during that period.[12]

During the push for Rome in the late spring of 1944, fractures of the hand accounted for 17.9 percent of all combat-incurred fractures at the 23d General Hospital and caused 12.4 percent of all orthopedic admissions.[13]

At the 6th General Hospital during one 6-month period, of the group in which wound and injury of the hand were the determining factors of hospitalization, 286 open wounds of the hand were treated; 83 involved only the soft tissues and 203 were compound fractures, distributed as follows:

| *Bones fractured* | *Type of fracture* | | |
|---|---|---|---|
| | *Compound* | *Simple* | *Total* |
| Phalanges | 125 | 6 | 131 |
| Metacarpals* | 65 | 8 | 73 |
| Carpals** | 13 | 7 | 20 |
| Total | 203 | 21 | 224 |

*Phalangeal fractures in 13.
**Metacarpal fractures in 7, phalangeal in 3.

Fractures of the hand observed on the orthopedic service at the 45th General Hospital for 1944 were:[14]

| *Bones fractured* | *Type of fracture* | | | |
|---|---|---|---|---|
| | *Compound* | *Simple* | *Total* | *Percent* |
| Phalanges | 118 | 16 | 134 | 35. 4 |
| Metacarpals | 179 | 15 | 194 | 51. 2 |
| Carpals | 35 | 16 | 51 | 13. 4 |
| Total | 332 | 47 | 379 | 100. 0 |

Associated injuries were present in 99 cases. These 379 fractures represented 10.6 percent of the 3,556 fractures treated at this installation during 1944.

At the 64th General Hospital, compound fractures of the hand accounted for 12.2 percent of 500 consecutive compound fractures, fractures of the wrist another 1.0 percent.[15]

That accidental injuries of the hand were more frequent than battle-incurred injuries is apparent in the comparative figures for the 6th and 12th

[12] See footnote 7, p. 95.
[13] Obletz, B.: Review of orthopedic service, 23d General Hospital. See also footnote 7, p. 95.
[14] Duncan, G. A.: Review of orthopedic service of 45th General Hospital, 1944. See also footnote 7, p. 95.
[15] See footnote 5, p. 88.

General Hospitals over the same 6-month period: At the 6th General Hospital battle casualties involving the hand accounted for 5.7 percent of all battle wound and injury admissions, and at the 12th General Hospital for 5.9 percent. Accidental injuries at the same installations over the same period accounted for 8.8 percent and 9.9 percent, respectively, of all nonbattle injuries.[16]

## INITIAL CARE OF HAND INJURIES IN FORWARD AREAS

A casualty who had received only a hand injury ordinarily cared for it himself on the battlefield with the material from his first aid kit. Early in the war it was the practice to dust the wound with one of the sulfonamides and to take by mouth the sulfonamide drug provided in the kit, but this practice was discontinued during the last months of the war (see Chapter I, p. 8). If the hand injury was only one of several injuries, and if the other injuries were more serious, the hand injury generally received little or no attention on the battlefield. The corpsmen's efforts naturally were devoted to the more potentially lethal wounds.

## INITIAL SURGERY IN A FORWARD HOSPITAL

The initial care received by a patient with a hand injury determined, in large measure, the ultimate functional results. Had the forward area surgeons always realized the importance of their part in treatment, the outcome in many cases would probably have been better.

*Debridement, Dressing, and Splinting.* The ideal treatment of an injured hand began with cleansing and debridement, always carried out under anesthesia. The blood pressure cuff was loosely applied to the arm as the anesthetic was being given. When anesthesia was complete, the arm was elevated and the cuff inflated to 230–240 mm. of mercury. The use of the blood pressure apparatus provided a bloodless field and permitted far more accurate identification of nerves and tendons, removal of foreign bodies, and other procedures than was possible in a field which had to be constantly sponged and in which hemorrhage was troublesome. The use of the pneumatic cuff was safer than the use of a tourniquet; the latter always carried an element of danger to the peripheral nerves.

When the blood pressure cuff had been inflated, the original dressings were removed and the wound covered with fresh sterile dressings while the surrounding skin was cleansed with bland soap and water. The wound was then thoroughly irrigated, examined, and evaluated.

Debridement was as conservative as possible. Blood clots and accessible foreign bodies were removed, as were obviously nonviable fragments of skin and detached, devitalized bone fragments. Nothing which could be conserved

[16] See footnote 7, p. 95.

was excised, since the hand contains so little excess skin and so little subcutaneous tissue that the loss of even a small amount of substance often made closure impossible. Also all fragments of bone which appeared to have attached periosteum were conserved since a certain bone length is essential for integrated movements of the hands. The use of skin grafts and flaps to cover exposed structures was possible when actually necessary, but this method had definite limitations. It was far better to save structures which could be preserved than to attempt to replace them later.

Large foreign bodies were removed at debridement whenever removal could be accomplished without too much difficulty. Accessory incisions served occasionally to facilitate removal of foreign bodies.

After the necessary debridement had been carried out, check was made for possible bleeding. The wound was covered and light pressure applied against it while the blood pressure cuff was released. The wound was carefully inspected in all areas, and if active bleeding points were found, the bleeding vessel only was grasped with forceps and ligated with fine silk or cotton. When it was certain that all bleeding had been controlled, the arm was again elevated and the blood pressure cuff reinflated. This technique insured that the wound was kept dry until the dressing was applied; it prevented postoperative hemorrhage and reduced the amount of post-traumatic swelling. A light packing of fine-mesh gauze was used to cover the wound. Tight packs and through-and-through drains were not used. A pressure dressing and splint were applied, and the patient instructed to keep the hand elevated at all times.

## REPARATIVE [17] SURGERY AT THE BASE HOSPITAL [18]

### Preoperative Routine

When a patient with an injured hand arrived at a base hospital, some concept of the extent of the wound could usually be obtained from the history, the operative record, and the roentgenograms sent with him to the rear from the forward evacuation hospital. Roentgenograms of fractures or foreign bodies were made additionally.

Even in the absence of injuries in other parts of the body, complete blood studies were made before closure of the wound was undertaken, since extensive trauma of the hand or forearm was sometimes accompanied by considerable loss of blood. Blood replacement, when necessary, was accomplished as early as possible so that secondary closure of the wound need not be deferred beyond the fourth or fifth day after debridement.

[17] Reparative surgery is the third-stage management of the wounded (the other two: first aid measures in combat zones, initial surgery in evacuation hospitals) performed in general hospitals in the communications zones. Its aim is to expedite wound healing and to minimize permanent wound damage.

[18] Base hospitals are located in the communications zones and may be either station or general hospitals.

## Surgery

*Inspection of Wound.* All reparative surgery was performed under general anesthesia with the blood pressure cuff in place. Only the outer dressings of the injured hand were removed before the anesthetic was administered. The digits were fully exposed and an attempt made to accurately estimate the nerve and tendon damage. The site of the wound usually furnished an accurate clue to the structures involved. Sensory loss in the digits was easily appraised by applying a cotton applicator to their lateral aspects. Motor involvement of the median nerve was determined by testing the action of the thenar muscles. Involvement of the ulnar nerve was ascertained by testing the adduction and abduction function of the fingers. Possible tendon damage was evaluated by testing the function of each digit at the metacarpophalangeal and interphalangeal joints. It was important that findings at this examination be carefully recorded, as they were needed for comparative postoperative evaluations and frequently helped to determine eventual disposition of the patient.

After the patient was fully anesthetized, the remainder of the dressings were removed and the hand thoroughly and carefully washed. The blood pressure cuff was then inflated and exploration of the wound undertaken. If inspection of the deeper structures was impossible without enlargement of the wound, incision was extended along the lines of skin cleavage, that is, along the lateral aspects of the hand, the digits and the wrist, or along the flexion creases of the palm. Midline and crucial incisions were avoided no matter what portions of the digits, hand, or wrist were involved.

*Removal of Foreign Bodies.* Accessible foreign bodies were removed at debridement. Both in the forward area and at the base, multiple tiny fragments which usually were not more than a millimeter in diameter, were left in situ (Fig. 36). Their removal would have required numerous mutilating incisions for which there was ordinarily no indication. Larger fragments were also left undisturbed unless they were located so as to interfere with function. For instance, a small particle resting near a joint or near a grasping portion of the hand might cause considerable pain when the parts were moved if left in situ. It was exceptional to find that metallic fragments alone had delayed healing; usually pieces of clothing or dirt were found surrounding the fragment. For this reason it was important to inspect the site carefully after the removal of any foreign body to make certain that no bits of nonopaque material had been left behind to be a source of further trouble.

When larger foreign bodies had to be removed, stereoscopic views of the hand were carefully studied, the incision was then planned in relation to the anatomic position of the fragment. As in inspection of deeper structures, incision followed the lines of skin cleavage, and if it had to be extended, extension was made along the lateral aspects of the palm, digits, or wrist. If a counter

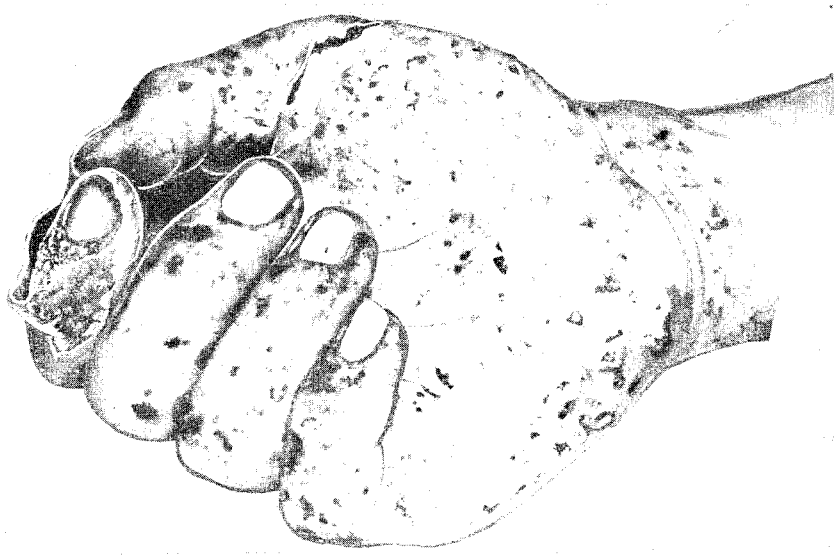


*Figure 36. Typical example of hand peppered with multiple small foreign bodies. Injuries of this sort were seldom incapacitating and as a rule most of the foreign bodies could be left in situ.*

incision had to be made to remove a foreign body at some distance from the original wound of entrance, the same rules were followed.

A bloodless field of operation, obtained by the use of the blood pressure cuff, was essential for the removal of foreign bodies. Small vessels, digital nerves, and tendons lie deep in the palm, and it was necessary that they be identified, held out of the way, and otherwise protected during search for the foreign body. They could be damaged irrevocably if blind searching was carried out in the face of hemorrhage. Blind probing with forceps was never practiced. When the foreign body was located it was removed with gentleness and care. Dragging it out of the wound without regard for the structures encountered along the way could produce serious additional damage.

*Need for Further Excision Determined.* Inspection of the wound determined whether further excision of skin and subcutaenous tissue was necessary. Further excision was seldom required in a wound which looked healthy, except possibly at the extreme angles of some of the flaps. Primary healing was unlikely to occur, however, if inspection showed the wound to be swollen, tense, and macerated, with the skin edges of flaps of tissue pale and curled under (Fig. 25). Further loss of tissue by excision was then inevitable, as this type of skin does not tolerate sutures but becomes necrotic and delays healing.

Viable flaps of skin were not removed. Their normal position could be restored and contraction and congestion prevented by a few judiciously placed

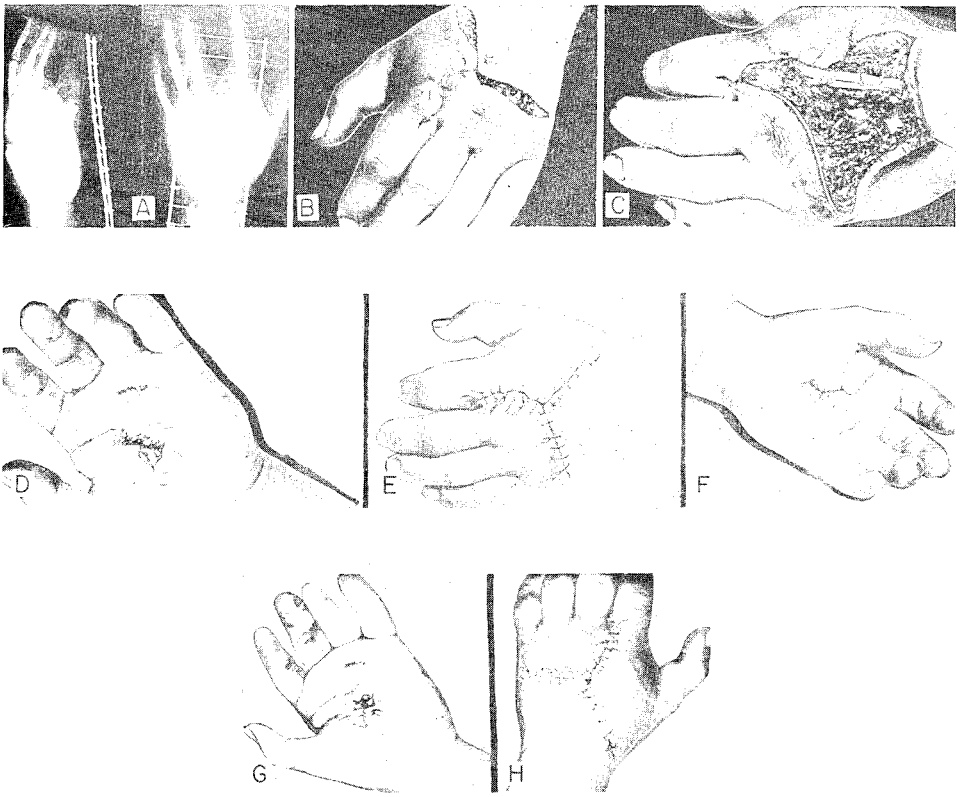



*Figure 37. Typical severe perforating wound of left hand with fracture of third metacarpal and division of extensor tendons. A. Roentgenograms of hand taken in evacuation hospital. B. Appearance of hand just before secondary closure, after optimal debridement. All possible soft parts have been conserved and a single suture has been judiciously placed at the apex of the dorsal wound to prevent retraction, curling under, and eventual maceration of the skin edges. C. Interior of dorsal wound at secondary operation. Note that the initial coverage of the wound has preserved the extensor tendon of the index finger. D. Palmar aspect of wound just before secondary closure. E. Closure of dorsal wound. F. Closure of palmar wound. G and H. Appearance of wounds 8 days after secondary closure.*

sutures (Fig. 37). As an alternative to suture, the flap was sometimes merely replaced and maintained in the proper position by a pressure dressing. This method held the flaps in normal position and at the same time protected exposed bones and tendons from contact with gauze dressings.

## Closure

After the deeper structures of the wound had been cared for, a check for possible bleeding was made in the manner already described. Closure was

effected by means of interrupted sutures. Care was taken to avoid tension on wound edges, no matter what technique of repair had been employed. No drains were used. If the operation had been carefully carried out, the wound was quite dry at this time and a pressure dressing could be depended upon to obliterate any remaining dead spaces, to control postoperative oozing, diminish outpouring of lymph, and prevent flaps of skin and subcutaneous tissue from becoming congested and swollen by encouraging the return of circulation.

## Techniques of Wound Closure

Serious problems often confronted the surgeon who had to close wounds in the soft tissues of the hand. His objective was to obtain complete healing within the shortest possible time so that function could promptly be resumed. Staged closing procedures were undesirable. Cosmetic effects were not the first objective in this phase of treatment; they might be the concern of the surgeon who performed the later reconstructive operation.

In numerous cases simple approximation and suture of the wound was possible (Figs. 38 and 39), but when there was loss of soft tissue and exposure of deeper structures, other methods were considered since coverage of these structures had to be accomplished. Whatever the technique, closure had to be

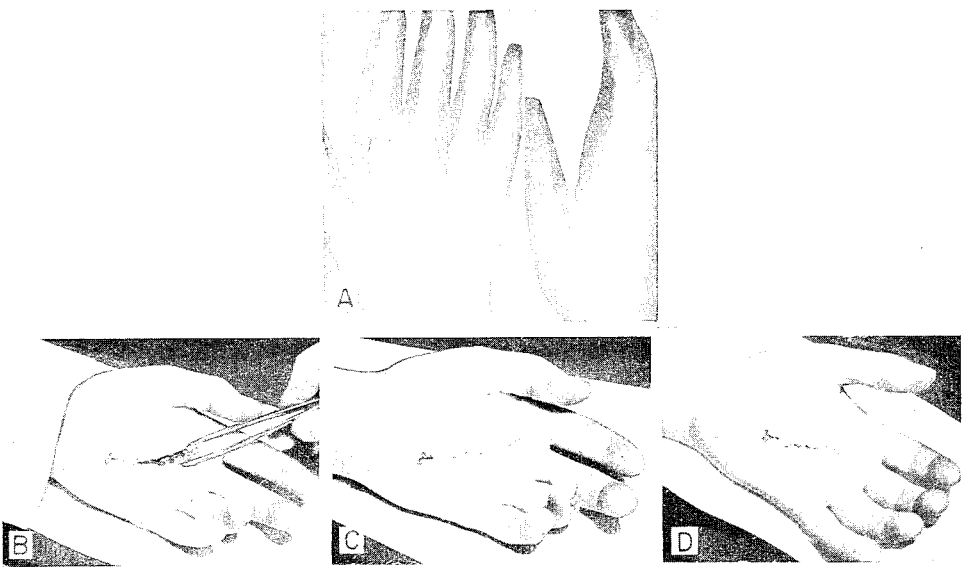



*Figure 38. Simple penetrating wound of left palm. A. Roentgenograms showing shell fragment in palm. B. Appearance of hand just before secondary closure. C. Closure of wound by suture after removal of foreign body. D. Appearance of healed wound 8 days after secondary closure. The hand had been placed on a dorsal splint to keep the tissues relaxed and at rest. Closure in this case was easily effected.*

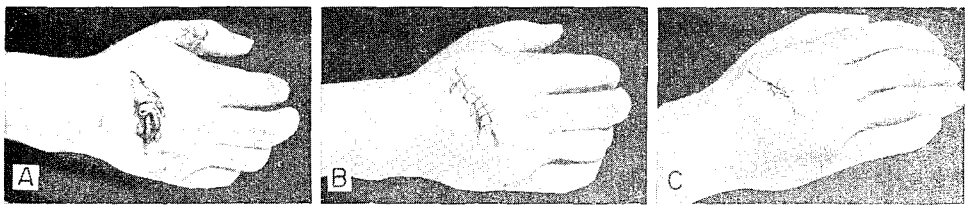



*Figure 39. Simple perforating wound of right hand without bone injury. A. Appearance of hand just before secondary closure, showing previous injudicious insertion of through-and-through drain. B. Appearance of hand after cleansing and closure. C. Appearance of hand 8 days later. Note that swelling is minimal, because of use of universal splint.*

accomplished without any tension on the wound edges. When tension was permitted, kindly healing did not occur, the sutures were likely to pull out and the resulting scar would be a handicap to the surgeon who had to undertake the final stages of reconstruction.

Loss of covering tissues of any amount in the hand, wrist, or lower forearm, precluded simple methods of secondary closure because there usually remained only a minimum amount of skin and subcutaneous tissue and what was left was difficult to mobilize. Neither the hand nor the wrist permits reduction of tension on wound edges by the method of undermining which has proved so useful in other parts of the body. Results were particularly unfavorable when this method was attempted in the digits or the palm. Necrosis of the wound edges usually resulted, and the tissue slough which followed delayed wound healing rather than expedited it.

Free skin grafting was often difficult because the bed available for the graft frequently consisted only of bone, tendon, or capsular tissue, and these structures were themselves often torn or fractured.

The optimal position for healing of injuries of bones and joints, that is, the position of function, was frequently not the optimal position for the closure of the wounds of the soft tissues. Closure of the skin could sometimes be obtained by flexing the hand at the wrist or flexing the digits without regard to any fractures present, but this was not a proper method of procedure, since the bones were left in a zigzag position. It was sometimes done, but surgeons who used such a plan failed to consider the hand as a single functioning unit and merely repaired one anatomical injury at the expense of another.

*Incomplete Closure and Skin Grafting.* In some cases in which the wound could not be closed by simple suture, it was found a good plan to close it at the angles and as far toward the center as was possible without tension. The remaining defect was then covered with adjacent areolar tissue and a graft applied. By this method exposed bones and tendons were covered and a satisfactory bed provided for the graft. Dorsal tendons covered with normal areolar tissue and volar tendons whose sheaths were intact furnished satis-

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factory beds for skin grafts. (Bone and capsular tissue as a rule were not satisfactory for this purpose.) Remarkably good results were sometimes accomplished if these structures were covered early with grafts (Figs. 40, 41, and 42), although this method was employed only when no other alternative was possible.

Closure of the perforating type of wound which consisted of a small, jagged wound in the palm and a larger wound of the same kind on the dorsal aspect of the hand (Figs. 25 and 37) was often attended with particular difficulty. The amount of tissue loss, while variable, was never very great on the palmar side because the firm palmar fascia held the skin firmly. On the dorsal surface the wound was larger and the tissue loss greater because the different consistency of the dorsal fascia permitted skin and subcutaneous tissue to be widely torn and separated from the hand. Fractures were often present (Fig. 37), and joints, as well as capsular tissues and tendons, were exposed. There were likely to be associated injuries of the interosseous muscles and nerves. The wrist and lower forearm often presented the same picture, and the volar surface was equally susceptible to wide losses of soft tissue.

*Rotation of Flaps of Tissue.* Large soft tissue defects accompanied by extensive bone and tendon damage were not suitable for simple suture or for incomplete closure and skin grafting. The best procedure in such cases was to cover the wound with skin and subcutaneous tissue obtained either by advancing

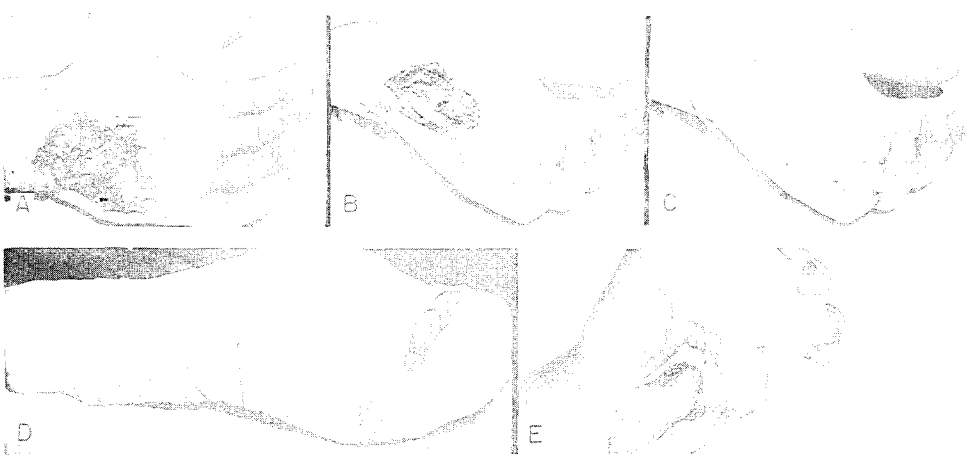



*Figure 40. Shell fragment wound of left hand, with avulsion and loss of soft tissue of hypothenar area. A. Appearance of hand just before secondary closure, 4 days after injury. B. Incomplete suture of distal and proximal segments of wound. C. Coverage of remaining defect with split thickness skin graft used as skin dressing. D. Hand on posterior splint, in position of function, with pressure dressing in place. E. Appearance of hand at initial dressing 6 days after secondary operation. The graft has not taken 100 percent, but spontaneous epithelization over the remaining small area can be anticipated.*

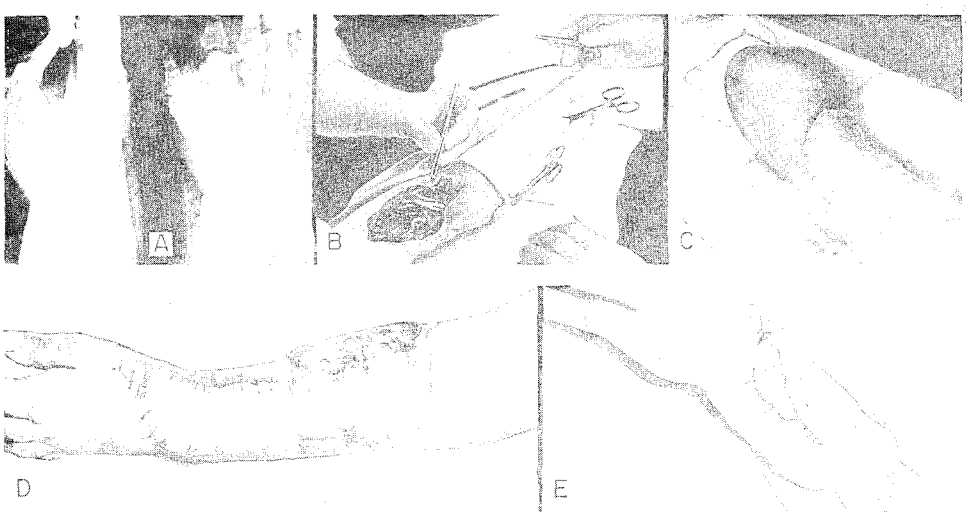



*Figure 41. Severe injury of radial-dorsal aspect of left wrist, with compound fracture of radius and joint capsule. A. Roentgenograms showing bone loss and loss of soft tissue at distal end of radius. B. Appearance of injured area just before secondary operation. Note large soft tissue defect on dorsal-radial aspect of wrist. C. Coverage of defect by shifting of thick flap of tissue consisting of skin and fat from dorsal-ulnar aspect of wrist. Donor area was then covered with split thickness skin graft. D. Appearance of wrist at first postoperative dressing. Original wound is covered by healed flap. E. Skin graft covering donor area of flap. The technique employed in this case often saved one operative step by covering at the secondary operation an area which would require satisfactory skin and subcutaneous tissue before secondary tendon repair could be done in the Zone of Interior.*

and rotating flaps of tissue from areas adjacent to the wound, or by a pedicle from the abdominal wall. In an overseas theater the former method was the more practical. These methods furnished tissues suitable for later reconstructive surgery and saved a step in the number of procedures which would later be necessary.

In palmar wounds rotation of flaps of tissue was seldom a practical procedure because the deep attachment of the fascia in this area makes mobilization of tissue difficult. The largest defects, however, most often occurred on the dorsum where the effects of the bursting type of injury were most evident. Wounds in the long axis of the hand, with longitudinal defects, conformed more easily to closure by the flap method than did transverse wounds. The technique (Figs. 41 and 43) was as follows: After determining from which side of the wound the tissue would be rotated, the wound was closed loosely by suturing the angles and the edges. The flap of tissue to be rotated was outlined

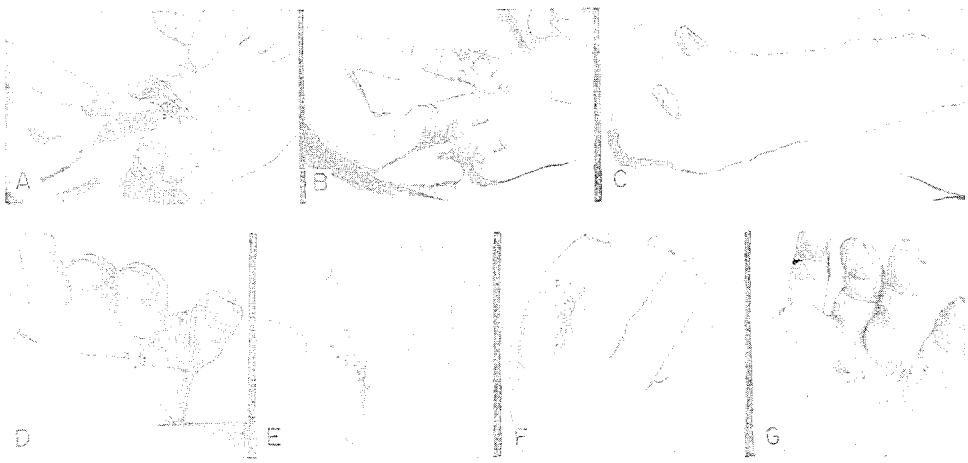



*Figure 42. Shell fragment wound of index and middle fingers of right hand. A. Appearance of hand just before secondary closure. Note absence of skin coverage over web and ulnar and volar aspects of index finger. B. Appearance of hand after secondary suture of wound, without undue tension, and coverage of open defect with split thickness skin graft. C. Hand on posterior splint, in position of function, with pressure dressing in place. D and E. Appearance of hand at first dressing 6 days after operation. F and G. Appearance of hand 6 weeks after injury.*

by incisions which followed the lines of skin cleavage. When they were extended proximally, they were placed along the lateral aspects of the hand and forearm. The flap was always made broad and thick. The base was wide and all the skin and subcutaneous tissues down to the deep fascia were evenly included. When the flap was shifted over the wound and sutured into place, care was taken to avoid excessive tension, which would jeopardize the local blood supply. The final defect, which was at a point removed from the original site of trauma, was covered with a split skin graft.

Experience showed that it was unwise to undertake closure by this method unless there was a reasonable chance of success. If it failed, and if the large rotated flap of tissue became necrotic, harm had been done. If, therefore, any doubt was felt about the outcome, some other, preferably simpler, method of closure was undertaken.

*Pedicle Flaps from the Abdominal Wall.* In an overseas theater the use of pedicle flaps from the abdominal wall had an extremely limited field in reparative surgery chiefly because of technical difficulties. The technique was most useful in cases in which damage was confined to the soft tissues on the dorsal aspect of the hand. The palm where tendons were often exposed was less suitable through pedicle flaps were effective in cases in which fingers had been amputated and the objective was to maintain palmar length (Fig. 44). They

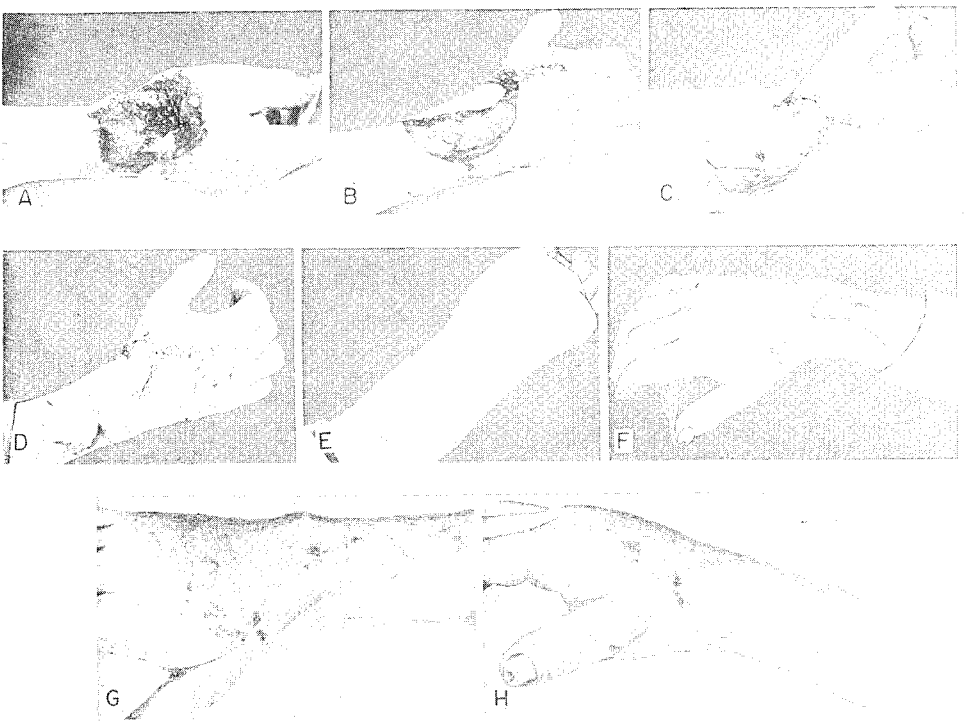



*Figure 43. Severe shell fragment wound, with compounding, of radial aspect of wrist and base of right thumb. A. Appearance of wound just before secondary closure, 5 days after injury. B. Creation of secondary flap from ulnar-dorsal aspect of defect, after partial closure of wound. Since the joint was open and the bones exposed, this technique was employed to secure satisfactory coverage with skin and subcutaneous tissue. C. Flap in place. Defect of donor area of flap is still visibile. D. Coverage of donor area of flap with skin graft. E. Hand on universal splint, in position of function, with large pressure dressing. F. Appearance of hand at initial dressing 5 days after operation. Bandage on upper forearm covers site of donor area of split thickness skin graft. G and H. Appearance of hand 2 weeks later.*

were also useful in maintaining length in an amputated thumb. In cases other than these it was better to secure healing as quickly as possible by some other method, so that the patient could be evacuated to the Zone of Interior for application of a staged pedicle flap. This was particularly true of cases in which fractures were associated with soft tissue damage. The bone damage could not be ignored, but the maintenance of the injured bones in a satisfactory position while the soft parts were healing usually made the pedicle flap method completely unworkable.

A pedicle flap from the abdominal wall was always formed with a broad base and included evenly all the skin and subcutaneous tissue in the area

selected. The hand was held attached to the abdominal wall for at least 3 weeks, during which time care was taken to avoid jeopardizing the blood supply by rotating or twisting the pedicle.

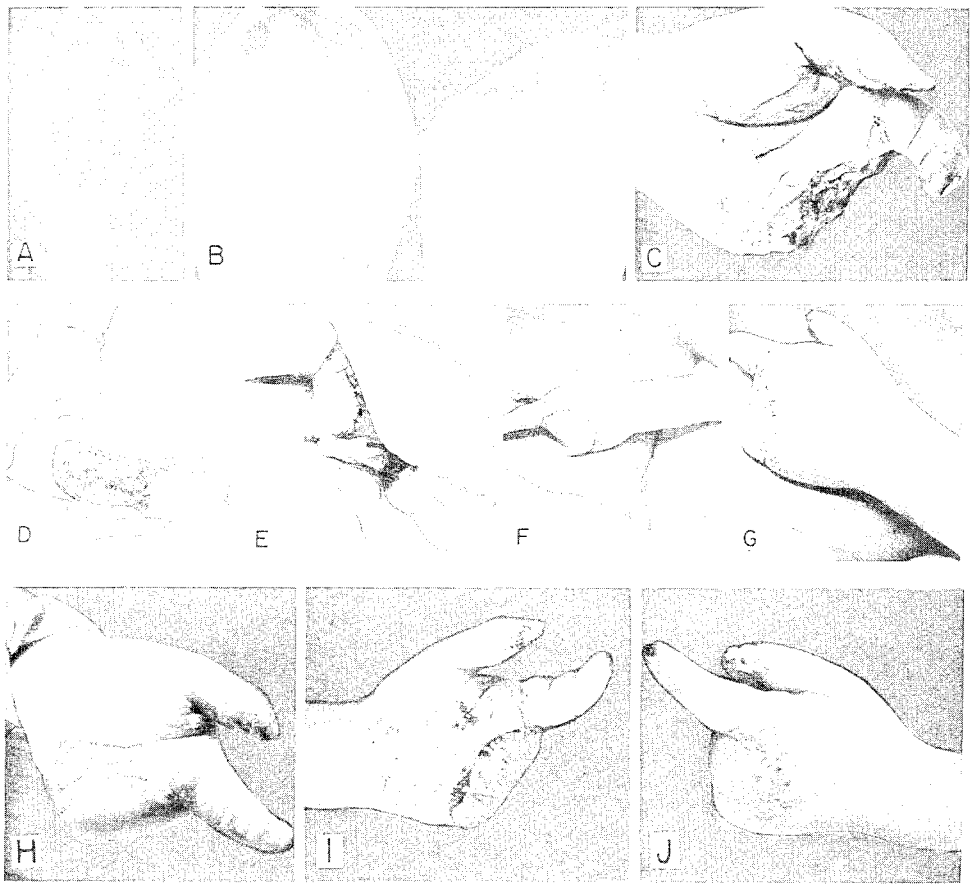



*Figure 44. Severe compound injury of left hand, with loss of middle, ring, and little fingers because of circulatory damage. A. Roentgenogram taken at evacuation hospital. B. Roentgenograms of hand in boxing glove splint for transportation. C. Appearance of hand just before secondary closure. D. Appearance of hand after cleansing and application of dressing, prior to placement of primary pedicle flap from abdomen. E. Accurate suture of primary pedicle flap from abdomen. F. and G. Appearance of hand 3 weeks later, after severance of pedicle flap. H–J. Appearance of hand 1 week after separation of pedicle flap. This case illustrates the use of a primary pedicle flap to conserve palmar length.*

## SPLINTING

### Splinting in Forward Areas

In forward areas immobilization was obtained by the use of a splint which was readily available, light, easily applied, and capable of maintaining the hand in a position of function.

These needs were satisfactorily met in a transportation splint in the form of a ladder made up of double thickness wire, flexible enough to be molded as necessary, and shaped to the palmar surface when the hand was in a position of function. Before the splint was applied, it was most important to ascertain that the distance from the heel of the wrist to the metacarpophalangeal joints was the proper length. The surgeon could determine this by placing his own hand on the splint and making certain that the apex of the palmar bend was at the level of the joints and not at the level of the web space, which would have put the metacarpophalangeal joints in hyperextension. Following debridement, the hand was laid on this splint, over which sterile dressings had been placed. If fractures were present the forearm was held firmly on the splint while the surgeon grasped the injured digits and gently pulled them until they were molded over the splint. This simple method practically always produced a reasonably good alinement of most fragments, whether of the metacarpals or metacarpophalangeals, or both.

Gauze was placed between the fingers at the web spaces, and the dorsum of the hand and forearm was covered with enough fluffed gauze or mechanics' waste to make a voluminous, bulky dressing. The hand, except for the fingertips and forearm, was then bandaged with stockinet or elastic roller bandage. The result was a firm, resilient dressing, which provided evenly distributed pressure, and was equally satisfactory for fractures and for soft tissue injuries. The degree of maceration was considerably less with this than with the more occlusive types; also, by frequent inspection of the exposed fingertips the status of circulation in the extremity could be determined.

When the thumb was involved in the injury a plaster mold was prepared at the beginning of the operation so that it was hardened and ready for use by the time debridement was completed. The normal hand in a position of function was used as a pattern and the mold made like the ladder splint just described for the palmar aspect of the hand and the volar aspect of the forearm. Application of the plaster-molded splint, including the reduction of the fracture and the use of pressure dressings, did not differ from the technique just described for the lattice splint.

Either of these methods (the wire-lattice splint or the plaster-molded splint) provided an effective method of obtaining alinement of fractures and immobilization of the injured hand in the forward area. Both were suitable for use with voluminous pressure dressings. Pressure to be effective and pain-

less required dressings of this sort. It could not be satisfactorily obtained by the use of a few layers of sheet wadding or gauze. Conversely, the application of voluminous dressings without a splint was likely to push the bone fragments out of line. Neither the wire-lattice nor the plaster-molded splint was an ideal method of immobilization but both served satisfactorily as transportation splints. When they were used with pressure dressings after reduction of the fractures they kept the hand in a position of function, held to a minimum the swelling inevitable after trauma and debridement, and made the patients far more comfortable than any of the splints formerly used in the Mediterranean theater.

## Splinting After Reparative Surgery

Immobilization in plaster was the most popular of the various methods used in base hospitals in the management of fractures after secondary closure. During the last months of the war a metal splint was introduced into several hospitals in the theater (Figs. 45 and 46) and used with great satisfaction. It was made by brace-shop technicians from a cement mold made in turn from the plaster pattern of the volar aspect of a normal hand in the position of function. A sheet of light aluminum was cut to approximate size, heated, and pounded into the shape of the pattern. The splint could be used for the right or the left hand.

The universal splint, as this splint was called, had many advantages. The palmar concavity helped to avoid the flat hand which frequently developed when the injured hand was molded by pressure dressing over the usual splint. Fractures could easily be reduced by laying the hand on the metal splint, pulling gently on the affected digits, molding the hand against the splint, and main-

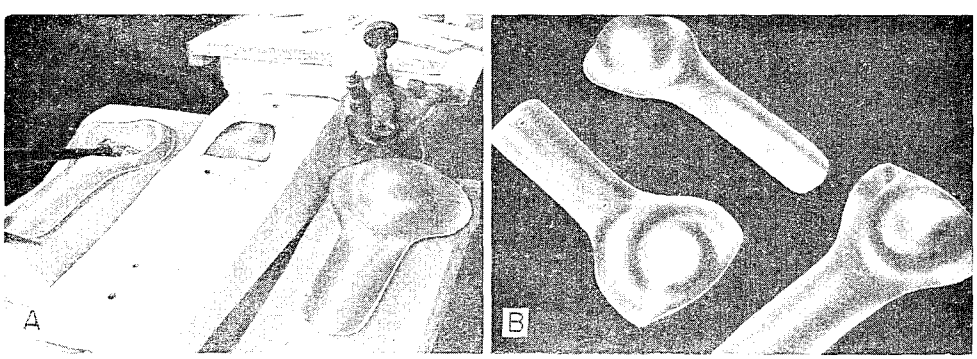



*Figure 45. Universal splints. A. Cement molds for malleable aluminum which, when heated, could be pounded into uniform sizes and shapes. B. Completed splints. Splints of this type proved extremely useful in an overseas theater for immobilization of fractures, crushing injuries, burns and frostbites. They could be sterilized, applied to either hand, and molded into any desired shape to meet the individual problem.*

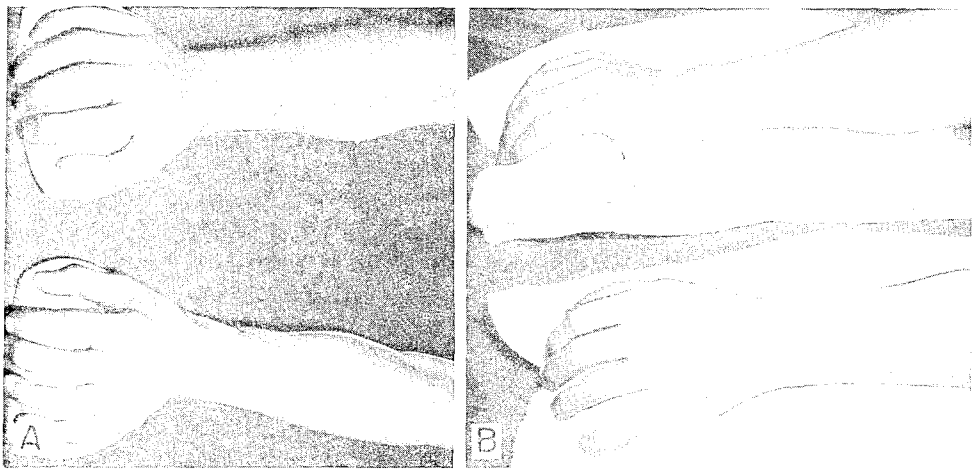



*Figure 46. Demonstration of use of universal splints. A. Hands in position of function over splints. Note alinement of fingers, dorsiflexion of wrist and flexion of all small joints of hands. B. Hands in position over splints, after padding has been applied, preparatory to application of pressure dressings.*

taining the position by a large resilient dressing (Fig. 47). This was a particularly useful splint in penetrating wounds of the metacarpal area. The palmar defect was closed and the fractures were treated as described, after which the dorsal wound could be closed without disturbing metacarpal alinement. Metacarpal or phalangeal fractures, including fractures of the thumb, were similarly managed quite effectively. If the thumb was not involved, there was constructed a somewhat comparable splint which provided the same stabilizing conditions for the wrist, hand, and digits, but which left the thumb free (Fig. 48).

The universal metal splint had still other advantages. Because it could readily be sterilized, it could be applied to the hand at any stage of the operative procedure. The surgeon could appraise accurately the relative positions of the fingers before pressure dressings were applied. Fractures reduced over this splint did not slip out of alinement, as sometimes happened when a plaster cast was hardening. When it was used, rotation of the fragments, overlapping, and subsequent shortening were extremely unlikely. It was advantageous in carpal fractures as well as in fractures of the bones of the hand (Fig. 49), since the wrist was held in the position of dorsiflexion until union had occurred and the soft parts had healed. Dressing of wounds of the soft parts was much easier with it than with a plaster splint. The splint eliminated the much-abused traction of fractures. Further, it prevented the angulation which was far too commonly seen when other methods were used.

Single finger splints were found unsatisfactory in the management of fractures of single metacarpal bones or phalanges. Single finger splints were

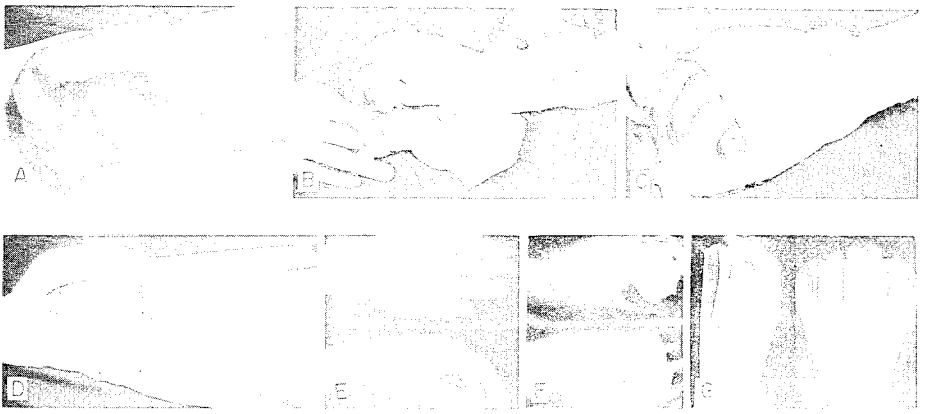


*Figure 47. Management of perforating wound of right thumb, with compound fracture of metacarpal, by means of universal splint. A. Appearance of hand just before secondary closure. B. Wound has been closed, hand placed on padded universal splint, and fracture reduced by simple traction applied to thumb. C. Completed pressure dressing, with splint incorporated and fingertips visible. Hand is in position of function. D. Appearance of hand 6 days after operation. Note minimal swelling. E and F. Roentgenograms of hand before secondary closure. G. Roentgenograms of hand after reduction and alinement of fracture and application of universal splint.*

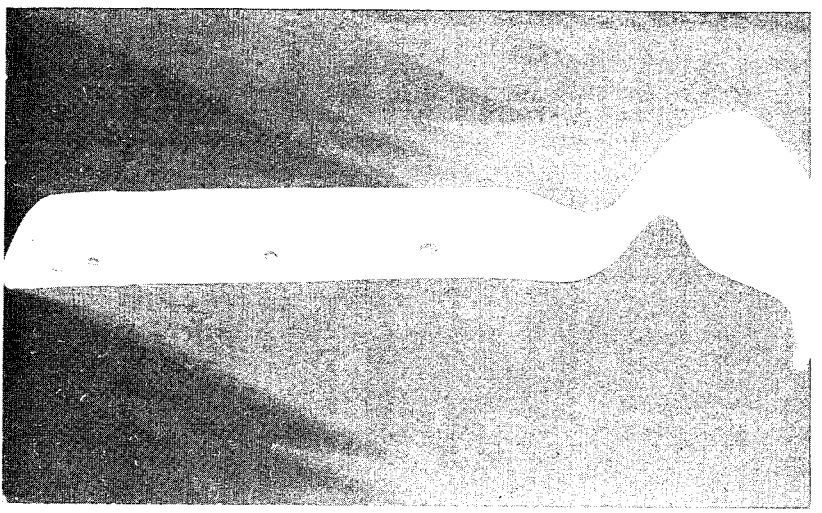


*Figure 48. Splint designed to hold injured hand in position of function and to provide convex surface for concavity of palm. This type of splint was useful when one or more of the second, third, fourth, or fifth metacarpals was injured, the thumb being uninjured.*

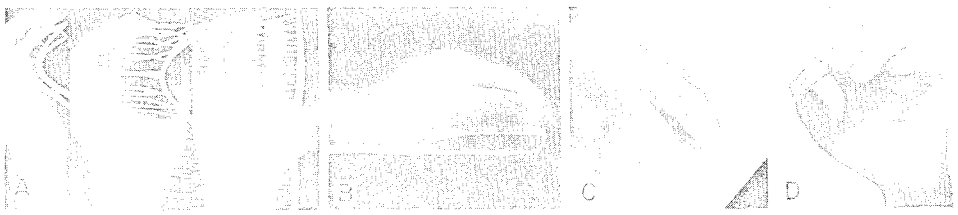


*Figure 49. Severe small perforating wound of left hand, with fracture and comminution into metacarpophalangeal joint of middle finger. A. Hand on transportation splint, in position of function, with good alinement of fracture. B. Hand on universal splint, after operation, in good position of function. C. Appearance of hand at time of initial dressing 6 days after operation. D. Hand in position of function. Note absence of swelling, as result of correct immobilization and use of pressure dressings. This case illustrates the possible severity of a small perforating wound.*

sometimes applied to permit free motion in the intact fingers, but the degree of edema was increased when they were used, and rotation at the site of the fracture frequently occurred. Whenever these conditions were not promptly corrected, flexion and grasping ability of adjacent fingers was affected. Numerous cases of this kind were observed in the theater in the course of the 1945 survey and the Civilian Consultant in Hand Surgery commented upon the number of patients returned to the Zone of Interior with hands in this condition.

Proper splinting for injuries of single metacarpal or metacarpophalangeal bones was to immobilize in the flexed position of function both the affected digit and the adjacent digit or digits. This method permitted more perfect alinement and a check of the proper length of the injured finger by comparison with adjacent fingers. Complete immobilization of the whole hand was regarded as essential in fractures of the bones of the fingers (Fig. 50) because the motion of the whole hand is so integrated that it is almost impossible to permit any movement without causing some irritation at the site of the fracture of the immobilized digit.

Extensive wounds of the palm which had to be closed by skin graft were put up in a dorsal wire-lattice splint, which could be shaped to hold the hand in a position of function (Fig. 51). This type was also used for immobilizing nerve and tendon injuries after they had been repaired.

*Institution of Motion.* The ultimate objective of all hand surgery is to restore function and function depends upon integrated movements. In the Mediterranean Theater of Operations particular attention was directed to the reinstitution of movement. There were wide differences of opinion, however, on how and when movement should be instituted. Some surgeons, as already mentioned, threw surgical principles to the wind, and did not splint the injured hand, but merely bandaged it and instructed the patient to use it constantly,

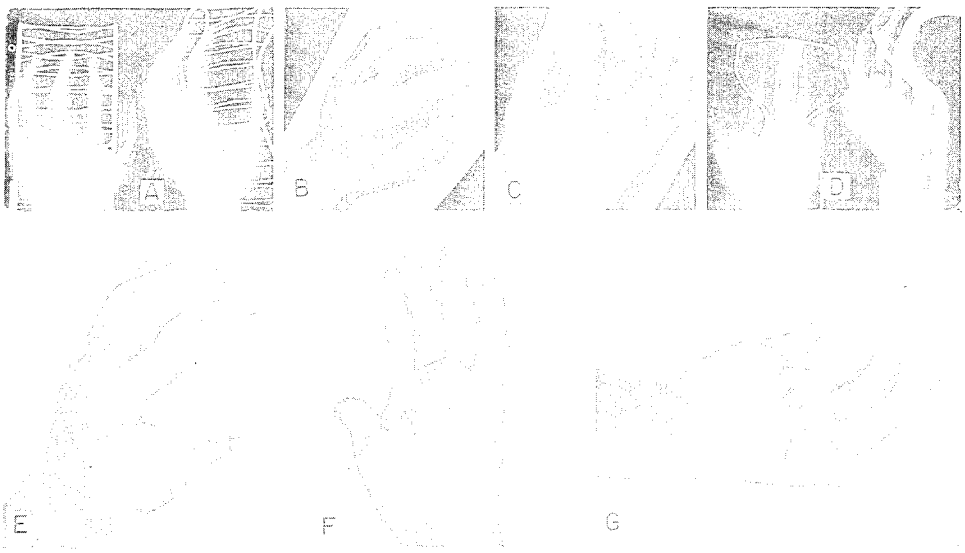


*Figure 50. Perforating wound of left third digit, with compound fracture of proximal phalanx and moderate bone loss. A. Roentgenograms of hand on transportation splint. B and C. Appearance of hand just before secondary closure. D. Roentgenograms showing postoperative alinement of fracture over universal splint. Note that alinement is good in spite of bone loss. E–G. Appearance of hand 5 weeks after operation. Clinical union is now satisfactory and there is some degree of function.*

to prevent "stiffness." Others advocated motion 3 or 4 days after injury, and at one hospital in the theater fractured hands were simply held over a roll of bandage for 5 days, after which free movement was encouraged.

Both of these were completely unphysiologic practices. In every injury there is an irreducible interval during which the injured part must be kept quiet to give the tissues time to lay down a framework of repair. Whether the injury is to the bone or soft issue, keeping the injured part in constant movement merely delays healing. When bones are involved the period of inactivity is necessarily longer than that for injuries of the soft parts because of the normal variations in the time required for healing of the different tissues.

The advocates of early motion who departed from these general principles did not achieve the results they sought. Whether the injury was a fracture of a bone or a wound of the soft parts, the first result of too early motion was additional hemorrhage, and because the lymph channels had not yet been reestablished hemorrhage was followed by an accumulation of fluid within the hand. Delayed healing was common and later edema was frequent. If the injury was a fracture, early motion almost invariably caused nonunion; frequently there was associated overriding and shortening.

At the other extreme, some surgeons delayed permitting motion until callus was clearly visible on the roentgenograms. This was an unnecessarily long delay. As a rule, 14 to 16 days was sufficiently long to wait. By this time healing of the soft parts had usually occurred and fractures had progressed to the stage of firm, though not necessarily solid, healing.

Ideally, at every dressing after operation the patient was instructed to move all the digits at all the joints; when this was done it was often possible to feel adhesions break within the joints and sheaths. The patient at this time, under supervision, went through all the finger motions possible, excluding those which would traumatize the site of the injury. Flexion was most important and was stressed. Seesawing of the joint was of no value at all; a full, complete range of motion was attempted.

Two weeks after the splint had been applied it was removed so that the hand could be examined and the site of the fracture tested for clinical union. If there was no evidence of union, splinting was continued for another week. When any degree of fixation was present at the fracture site, a smaller metal strip molded to retain the part in the same position was substituted for the original splint (Fig. 52). With this splint a lighter pressure dressing could be applied and the uninvolved fingers or other parts of the hand could be freed so that motion and use could be begun. At the end of the third week the fracture was again examined and if clinical union seemed well advanced the splint was removed during the daytime, but was applied by the patient each night as a protective measure during sleep. On the average this policy permitted motion to be instituted about 3 weeks after the secondary operation.

Once movement was permitted in was explained to the patient that the ultimate restoration of function would be largely dependent upon his own efforts. He was instructed in the motions to be employed. These were all purposeful and were graded to coincide with the continued healing process and stabilization of the fracture. The patient was told exactly what the surgeon hoped to achieve, and the disposition planned for him, so that he had no temptation not to use the hand in order to delay his return to duty.

As healing progressed and smaller splints could be used, more use of the hands was expected. Patients who were inclined to favor the injured hand, or who were reluctant to use it freely, were sent to the workshop or the hobby shop as soon as possible. Also there were a multitude of duties about the ward which were excellently suited toward encouraging movement. Patients with hand injuries helped to feed other patients; they washed dishes because dishwashing in warm soapy water particularly overcame stiffness of muscles and joints. It was important to make the patient understand that the work he was doing was a therapeutic measure and not a punitive assignment.

When the joints were unusually stiff, movement could often be improved by the use of splints with elastic slings, which exerted a constant resilient pull

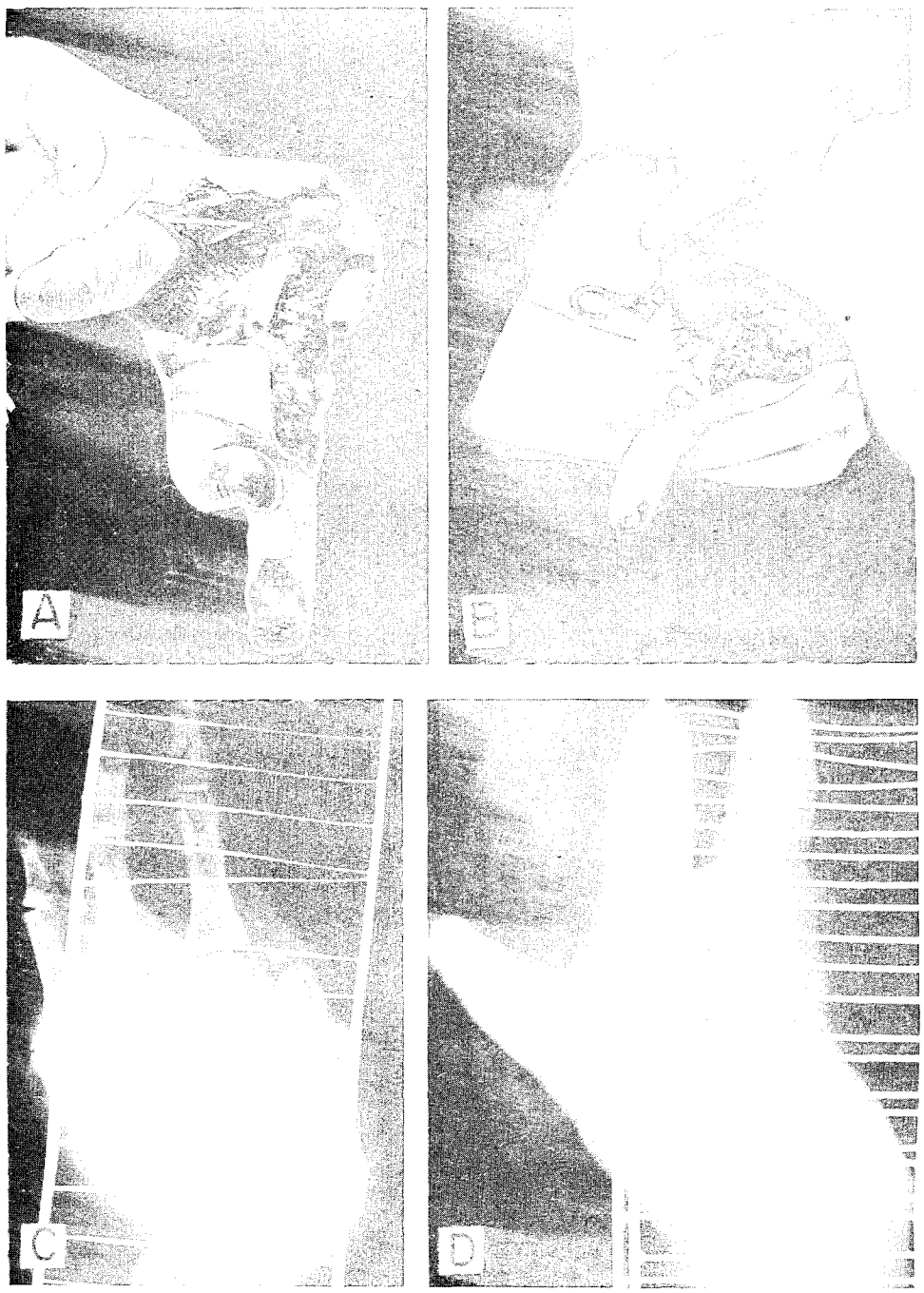



*Figure 51.*

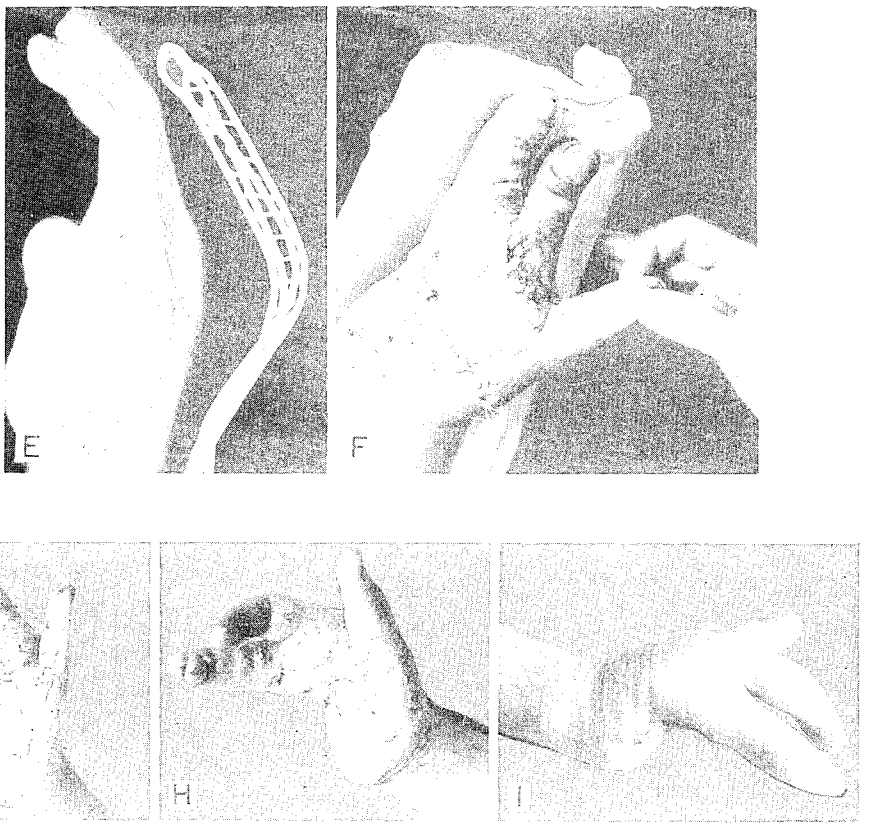



*Figure 51. Hand grenade injury of right hand resulting in incomplete amputation, loss of most of covering tissue of palm, and compound fractures of index and middle digits. A. Appearance of hand just before secondary closure. B. Incomplete closure of wound, coverage of remaining defect of palm with split thickness skin graft. C. Roentgenogram of hand on transportation splint. D and E. Roentgenograms of hand on postoperative splint. F. Appearance of hand at first postoperative dressing, showing healing of soft parts. G–I. Appearance of hand 4 weeks later, showing soft tissue healing and clinical union of fractures.*

on the injured digits. A glove with rubber straps worn at night was useful in accomplishing interphalangeal relaxation. These simple measures were found more effective than manipulation and passive stretching under anesthesia.

Whenever possible, some method was employed to measure the degree of motion in the injured part so that the patient as well as the surgeon could see what was being accomplished. A crude apparatus was quite satisfactory for this purpose and notation was made on the record each time the range of motion was tested.

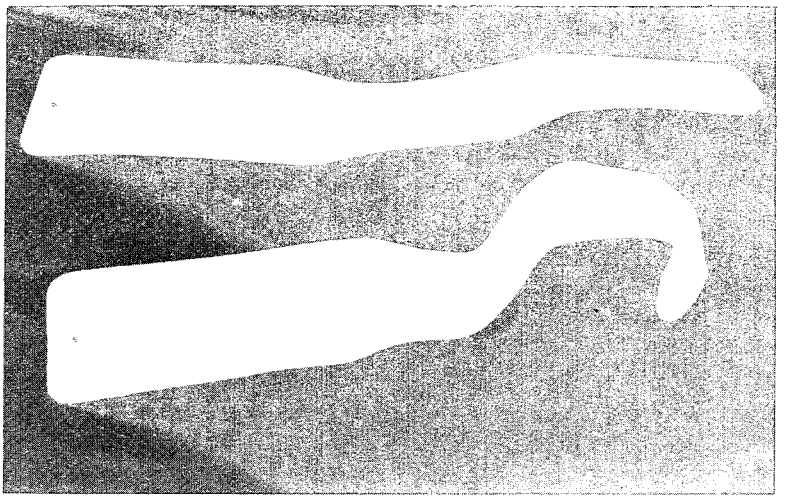


*Figure 52. Small aluminum splint made of malleable aluminum salvaged from wrecked airplane. These splints, which were made in various sizes and shapes, could be sterilized and molded as necessary in the individual case to provide relaxation and rest for injured parts.*

How successful all of these measures were, depended upon the patient himself. Unless he was willing to cooperate and would exercise his hand as he was instructed to do, the most expert surgery was likely to be unsuccessful or less successful than it might have been. Most surgeons recognized the importance of the patient's role in his own treatment, and made every effort to secure his cooperation, but how to correct an uncooperative attitude and return an unwilling soldier to duty was not always a simple matter.

## PHYSICAL THERAPY

Physical therapy was not used routinely in hand injuries in the absence of nerve involvement. Patients were referred for physical therapy only on definite indications, and it was never prescribed merely for lack of something else to do. Certain patients were actually harmed by physical therapy. If they received treatment daily, or on alternate days, they felt that they were not required to work actively toward their own recovery, that heat, massage, and passive exercise, carried out by physical therapy aides, were all that was necessary. As a result the hand would be neglected and would become stiff in the intervals between treatments.

In properly selected cases the physical therapy department furnished effective assistance in achieving optimum results. Usually a combination of physical therapy and hobby shop activities was devised. It was essential that the physical therapist understand what the surgeon wished to accomplish and that the surgeon understand what the physical therapist could achieve. It was par-

ticularly important that too energetic attempts to restore motion should not be permitted. In such cases, particularly if joints were involved, additional trauma was heaped upon already damaged parts. A good rule to follow was that if passive motion produced pain, it was likely to be doing more harm than good.

The whirlpool bath was never prescribed for patients with hand injuries.[19] The heat which it provided to the part was desirable, but the dependent position seemed to increase congestion and swelling. Better results were achieved with a combination of heat, massage, and active exercise of the whole hand.

The occasional tendency to label as physiotherapeutic failures the poor results achieved in many wounds of the hand was not justified. The extent of the initial injury and the type of surgery performed at debridement and afterward were the factors which chiefly influenced the outcome. Physical therapy could not overcome the handicaps of poor technical surgery or poor surgical judgment.

## FRACTURES

*Simple Fractures.* The ideal management of simple fractures of the hand followed in general the method of treatment used for similar injuries in civilian life. Impaction was more frequent in combat-incurred than in fractures sustained in civilian life and had to be overcome when reduction was done if shortening of the affected part was to be avoided. Roentgenograms were carefully studied before reduction was attempted, and general anesthesia was employed as necessary. Immoblization in the position of function was maintained until clinical bony union was well advanced. Immobilization was not continued until roentgenographic evidence of callus appeared. Results generally were good.

When a single finger or a single metacarpal bone had been injured, rotation of the fragments was avoided by splinting the affected finger to the adjacent intact member, to keep the digits in their normal relative positions. Smaller splints were applied when danger of fragments slipping out of position had passed. Oblique fractures were accurately reduced and then held in place by pressure dressings. This method not only kept the fragments in proper alinement but also reduced post-traumatic swelling, which occurred almost as often in simple as in compound fractures.

*Compound Fractures.* Compound fractures of the hand always introduced serious problems. The injuries were usually multiple; the bones were likely to be extensively comminuted, and associated damage to soft tissues, nerves, muscles, tendons, and joints was common. The widespread reaction of adjacent tissues often bound the movable structures of the hand in dense scar tissue and made free motion almost impossible. The bones were often so

[19] There was no unanimity of opinion on the efficacy of the whirlpool bath in the treatment of injured hands as later chapters will show.—Ed.

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severely shattered and the joints so extensively involved that functional disability following injury was almost inevitable. Unless the fragments of bone were actually free and unattached, they were permitted to remain in situ, to maintain as much length as possible. When comminution and shattering were excessive, fragments of bone still attached by periosteum were packed together, so that spicules would not be left projecting at angles into the muscles and tissues of the hand. That this practice was safe was shown by the fact that failure to heal because of the presence of dead bone fragments was never a serious complication in the Mediterranean Theater of Operations.

Closure of wounds of the fingers over fractures was often difficult since the paucity of tissue in this area prevents the shifting of flaps. In many cases the only recourse was incomplete suture and the application of free skin grafts, a method which usually produced gratifying results. If grafts were not used, healing of the soft parts was likely to be sluggish and healing of the fractures correspondingly slow. Immobilization for long periods of time was therefore necessary.

Fractures of the metacarpal bones were usually caused by penetrating or perforating wounds associated with extensive loss of soft tissue. In this type of injury it was possible to maintain the fragments in the proper position by the use of a molded-metal splint, but shortening could not be overcome by traction or any other device. If the bone loss was extreme, a false joint was frequently created which later had to be corrected by bone graft. If shortening because of a bony defect occurred in association with the functional loss of tendons and small muscles, the involved finger was frequently left semiflexed at the metacarpophalangeal joint, with corresponding limitation of the functions of flexion and extension. Such serious disability was so general in cases of this kind that it was uncommon for a casualty with such an injury to be returned to any type of duty in the theater.

Following operation constant vigilance was necessary to be certain that the proper position of the hand was maintained. The relative position of the digits on the splint and their relation to one another served as clues in achieving the proper position, but accurate evaluation could be determined only by repeated roentgenograms. Surprisingly few patients required further manipulation of their fractures when proper attention had been directed toward accurate reduction at the time of closure of the wound. In the occasional patient where the hand was found in poor position on the splint, the dressings were removed and the position changed. Care was taken to see that the small joints were flexed and the metacarpal arch maintained. It was necessary to keep all of the joints evenly lined up and properly flexed. Hyperextension at the metacarpophalangeal joint occurred whenever the hand slipped back on the splint or when the pressure dressing was not effective.

*Traction.* Although during the course of the war numerous articles appeared in the medical literature advocating the use of traction in the manage-

ment of fractures of the hand, this method was used less frequently in the Mediterranean Theater of Operations as experience with these injuries increased. Traction was frequently employed unwisely, over too long periods of time, and with the hand in extension. Actually there is no point to the continuation of traction after the reduced fragments have been held in place long enough for fixation to occur, usually 14 to 16 days in battle-incurred injuries (Fig. 53).

Traction in the management of hand injuries in an overseas theater had numerous disadvantages:

1. It was difficult to care for associated wounds of the soft tissues when the traction apparatus was in place; frequent removal and reapplication was a time-consuming task, and particularly objectionable in hospitals in which the patient load was heavy.

2. Traction did not prove to be an effective means of stabilization. Unless a definite pull was exerted and maintained at all times, instability at the site of the fracture and rotation of the fragments resulted.

3. It was always accompanied by the possibility of pressure necrosis.

4. Traction produced no better results than those achieved with far less effort and difficulty by molded splints and pressure dressings.

When traction was properly employed, reduction was accomplished, as described, the position of the fragments was checked, the involved digit or other injured part was placed in a position of function, and the traction directed toward the forearm over a molded-plaster or metal splint. Fractures

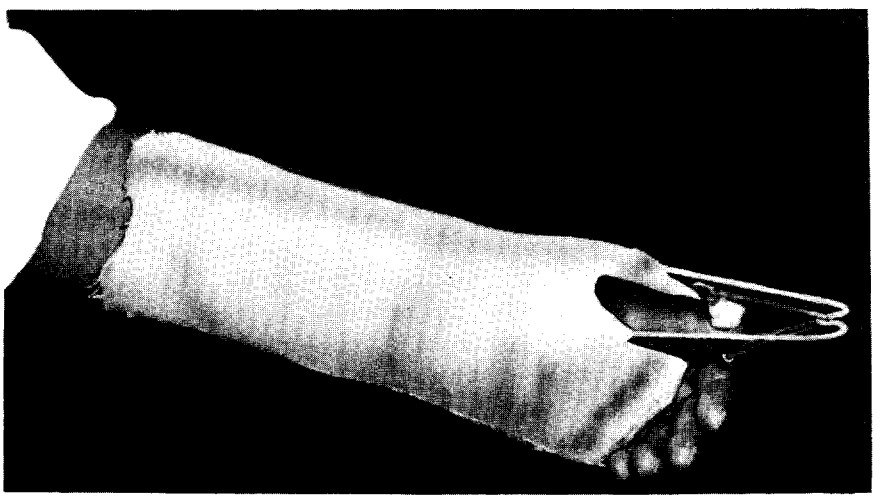


*Figure 53. Plaster cast with traction applied for fracture of base of left thumb. Photograph shows condition of cast 5 weeks after injury. The cast is loose, the injured thumb is not immobilized, and the hand was found to be greatly macerated. Questioning revealed that this patient always released the traction at night.*

extending into the small joints furnished the most logical indication for the use of traction, though its employment often required the transmittal of the pull through several joints.

Skeletal traction was not used at all. The use of wires, needles, and similar devices through the phalanges, and of pins and sutures through the pulp of the distal phalanges, was eventually regarded as contraindicated in the forward areas and was seldom justified at the base hospitals. In the 1945 survey numerous cases were observed in which improperly applied wires or needles traversing the interphalangeal joints had damaged the digital nerves, while traction through the pulp of the distal phalanx had often left a residual tender scar because the apparatus had torn through.

## NERVE AND TENDON INJURIES

The hand service in the theater military hospitals was never without a certain proportion of patients with injuries of the nerves and tendons. In the final 156 admissions to the hand service at the 12th General Hospital, there were, exclusive of amputation cases, 19 patients with nerve injuries, 13 with tendon injuries, and 8 with injuries of both structures.[20] Ten of the 19 nerve injuries involved the median or ulnar nerves at the wrist and the remainder the nerves of the hand. The tendon injuries included both complete and incomplete varieties; tissues were usually jagged and frayed, and the tendons denuded of sheath or areolar tissue.

Nerve and tendon injuries were recognized as common complications of injuries to the hand but few repairs were undertaken. For the most part the results of this type of surgery were poor. Although many surgeons would have liked to perform these operations, they could seldom be done in the short time allotted for hospitalization in an overseas theater.

Few injuries to the nerves and tendons were diagnosed in the forward areas except in the obvious instances of major damage to the forearm and wrist. Occasionally a divided tendon seen at operation was mentioned in the operative note. Some conception of the pathology could be gained from the anatomical location of the wound, but it was unfortunate that a more earnest attempt was not always made at the time of either the initial or reparative surgery to determine the exact condition of the nerves and tendons since this had an important bearing on the ultimate disposition of the patient. Possible tendon injury could have been assessed readily by testing the motion of each joint, while tests for motor and sensory function could have established the status of the nerves. Both types of nerve injury were common at the wrist, while within the hand proper only the sensory function was usually affected.

*Early Care of Divided Nerves and Tendons.* Initial primary nerve and tendon surgery of battle-incurred injuries was not feasible due to the associated

[20] See footnote 7, p. 95.

injury to the soft parts and bone and because of the time needed for careful, meticulous repair. Further, complete closure of the wound should be performed and this did not prove to be successful under field conditions in the theater. In injuries involving the nerves and tendons it became the general policy to treat the wound of the soft parts by debridement and immobilization followed by delayed closure of the wounds; to reduce or complete the reduction of fractures when the reparative surgery was done; to immobilize the extremity again and to ignore until later the nerve and tendon injuries. The practice of inserting identifying sutures in the ends of divided nerves and tendons was found to be unnecessary and not entirely free from harm because it increased the local reactions.

The civilian type of hand injury in which nerves and tendons were injured by knives, glass, tin cans, and similar wounding agents was encountered frequently in active, young men. Because the wounds were sharply lacerated in contrast to the bursting type of injury in battle-incurred wounds, soft tissue and bone damage was relatively uncommon, and the local reaction correspondingly less. It would have been entirely practicable to repair primarily most nerve and tendon injuries of this sort had it not been for the fact that such casualties were usually taken to station hospitals, to which highly experienced surgeons were not assigned. Repairs attempted by any but experienced surgeons were usually incomplete or otherwise inadequate, and the end results not good (Fig. 54). When there was doubt as to the advisability of repairing

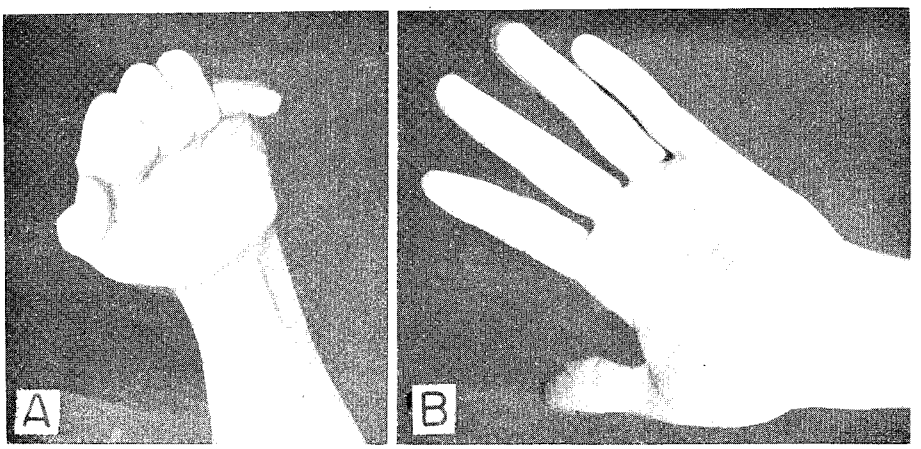



*Figure 54. Oblique wound of hypothenar area of left hand, with division of flexor tendons and digital nerve to fifth finger. A. Appearance of hand following secondary repair of nerve and tendons through crippling midline incision traversing flexion creases of digit and palm. B. Limited flexor function following careless repair, with lack of attention to principles of proper placement of incision.*

these structures or of undertaking such an operation, the best practice was to clean the wound, debride it, close it loosely, splint it, and then transfer the patient to a hand center where delayed repair could be performed. After healing had occurred a delayed repair could be done with satisfactory results.

*Late or Delayed Care.* The soft parts had to be soundly healed and the fractures in good, firm alinement, with all surrounding thickening and edema at a minimum, before late or delayed repair was considered. The condition of the soft tissue dictated the optimal time for exploration and suture of tendons and nerves. Too early repair meant vascular scar tissue and sluggish healing with edema of the deeper structures. For the average patient 4 to 5 weeks seemed to be about the optimal time. To be successful the nerve or tendon had to be placed in a soft bed at the time of suture and only the most mild type of wound, well healed, would satisfy this requirement.

Before operating on the tendons the involved joints had to be freely movable and this factor demanded early consideration so that obtaining motion or mobility of the joint did not delay the operation. During convalescence the patient was instructed in the proper manner to get the joints mobile and made to understand the necessity for doing this. At the same time his interest in securing function was stimulated. While waiting for the soft parts to heal, the muscles and the joints involved in the motor nerve injury were protected by a light metal splint. This was fashioned from light aluminum and was removable to allow the patient to wash and to use his hand. Washing was an excellent method to obtain use and mobility of the joints and seemed to aid in resolving the surrounding induration and thickening. It was a purposeful type of action and one which the patient readily understood and performed for himself. Physical therapy was used but not routinely, as has been said before; some patients were too apt to rely on others to gain results.

Before starting on repair of these injuries it was necessary to know that there would be sufficient time allowed for the operating surgeon to give continuous care to the patient until some recovery was noted. Failure to allow for this proved a handicap both to the patient and to the surgeon due to receive him soon after repair had been performed, for only the operating surgeon himself was familiar with the variables influencing the outcome in each individual case.

The incision had to be well planned and the surgeon prepared to enlarge the wound when necessary. Simple suture of the nerves and tendons was not always possible and the surgeon had to have the necessary experience to employ grafting or use some other plastic method. Tendon repair had to be performed, using the finest suture material possible to hold the tendon opposed until union had occurred. Complete rest was required for the digit, hand, and forearm, until the site of tendon suture was firm; otherwise early motion allowed the suture to pull through or encouraged a thick callus to result.

Relaxation of the sutured tendons was obtained by a dorsal splint until firm union had occurred. The splint was maintained for about 3 weeks and was slowly altered over a period of a week to allow graduated and controlled motion. This planned alteration of the splint was closely adjusted to the increase of the tensile strength at the site of tendon suture. In cases of extensor repair the volar splint to protect the tendons was used for about 4 weeks and then continued at night only to protect the fresh tendon callus from being stretched by the intact and stronger flexor group.

Commonly—too commonly in the Mediterranean theater—the tendon was sutured carefully but continuous motion was started. Immediately after surgery the patient was able to move the finger, but in 2 or 3 days the motion ceased and was never regained. Usually the site of the suture had been able to withstand the motion for the first few days after surgery, but after that the holding power of the tendon for the suture rapidly dropped and allowed the suture to pull through, leaving the ends separated.

Evans [21] of the 26th General Hospital summed up the problem of tendon surgery of the hand as follows:

> This class of injury presents, in our mind, one of the most serious problems with which we must deal. The exigencies of military service require the early return of the casualty to duty. That soldier whose civil occupation is industrial may assist in making the decision for amputation of a finger to facilitate early functional recovery, but another may desire that every effort be made to save a part despite residual loss of function. It is our candid opinion that late tendon surgery, entailing as it does prolonged hospital stay, is seldom justified in this Theater and for the most part such surgery has been done in the hope of early rehabilitation to a key position or as a procedure begun here for further convalescence in the Zone of the Interior. . . .

In 12 of his patients, 3 were returned to the Zone of Interior because of poor results or failures, while 9 were returned to duty with the following end results: 2 stable but unimproved; 4 slight improvement; 3 good function. Throughout the theater about 50 percent of the cases operated upon for tendon repair were sent back to the Zone of Interior.

## AMPUTATIONS

*Indications and Contraindications.* Many compound fractures of bones of the hand involved the small joints, either directly with loss of the joint surfaces, or indirectly with comminution of the fracture extending into the joint. In both instances motion in these joints was impaired. Amputation for such injuries themselves were not indicated particularly if only a single joint was affected and if the vascularity of the tissues remained good. It was not at all unusual to find that some serious fractures which extended into the

[21] Evans, E. T.: Elective surgery of orthopedic conditions in a general hospital servicing the Air Forces overseas. M. Bull., MTO 3: 236–240, Jun 1945.

joint eventually healed with sufficient motion to have fully justified the policy of conservation.

The question of amputation also arose whenever phalangeal fractures were associated with division of the flexor and extensor tendons. Even if the fracture was extensively comminuted and if there was a considerable loss of bone, amputation was not employed if the tissues were viable. Amputation could be done later as an elective procedure if conservatism proved an unwise choice.

Hand grenade injuries were particularly mutilating, and parts of several digits were likely to be amputated traumatically. Under these circumstances, preservation of all the remaining digits, even if they were the site of multiple fractures, was most desirable. This again was on the principle that any stump or portion of the hand with intact sensation (and prehension—Ed.), regardless of its appearance was better than any prosthesis then available (Figs. 34, 51, 55, 56, and 57). Unsightly and functionless parts could be removed later if the decision not to amputate them originally proved unwise. Closure was by simple methods when this was possible (Fig. 58), or by skin graft (Fig. 59).

When the wound was in the palm of the hand and was associated with loss of metacarpal bone and with tendon damage, amputation of the affected finger, even if it was undamaged, was sometimes the wisest course. Whenever any digit was amputated, all available skin was saved from the soft tissue defect (Fig. 60).

Under no circumstances was amputation performed through the metacarpal of the thumb in the absence of definite vascular impairment. When the second or the fifth metacarpal bone had been injured, amputation was done through the site of the fracture. When either of the middle metacarpals was involved, or both, amputation was preferably done at the level of the metacarpophalangeal joint, to preserve the natural transverse bony arch of the palm and avoid shortening. The V-shaped type of amputation through the palm proved highly unsatisfactory. It permitted adjacent fingers to fold inward and rotate, greatly interfering with function. Moreover, a man who had lost one or more digits and whose palmar surface was shortened had difficulty holding objects even when the thumb was intact. Most patients who had been submitted to the V-shaped type of amputation had such crippling results that they had to be returned to the Zone of Interior.

Amputation should never have been considered, as it occasionally was, as the proper treatment for infection whether of the soft parts or of the bones of the hand. Proper treatment of infection was always conservative, with incision and drainage when localization had occurred. When osteomyelitis had developed, the proper treatment was to wait for sequestration and then to remove the dead bone. Amputation was withheld not only because of the risk of spreading the infection when it was performed but also because a

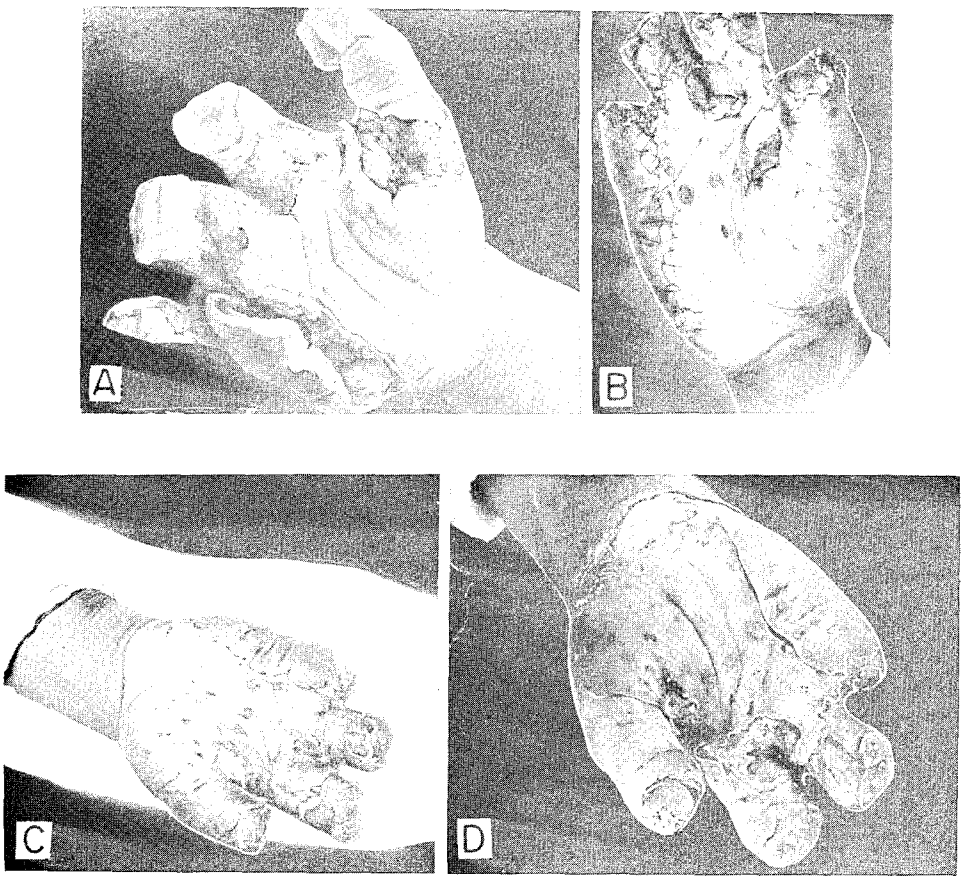



*Figure 55. Typical hand grenade injury of right hand, with loss of skin, amputation of tips of thumb, index, and middle fingers and complete amputation of ring and little fingers. A. Appearance of hand just before reparative surgery. B. Appearance of hand at initial postoperative dressing. Wound has been closed by suture and application of skin grafts to soft tissue defects over amputation stumps, web of index and middle fingers, and web space of thumb and index finger. C. Appearance of hand 2 weeks later. D. Appearance of hand 4 weeks later. This case illustrates the possible salvage of a badly damaged hand and indicates the inadvisability of performing radical amputation merely because it simplifies surgical management.*

return of function, sometimes to a surprising degree, was often observed when healing had occurred.

In some instances of burns and frostbite, amputation could not be avoided because the injuries were of such depth that gangrene of the fingertips had occurred. In these cases the rest of the hand was usually more or less involved in the injury. The procedure of choice was to permit the gangrenous

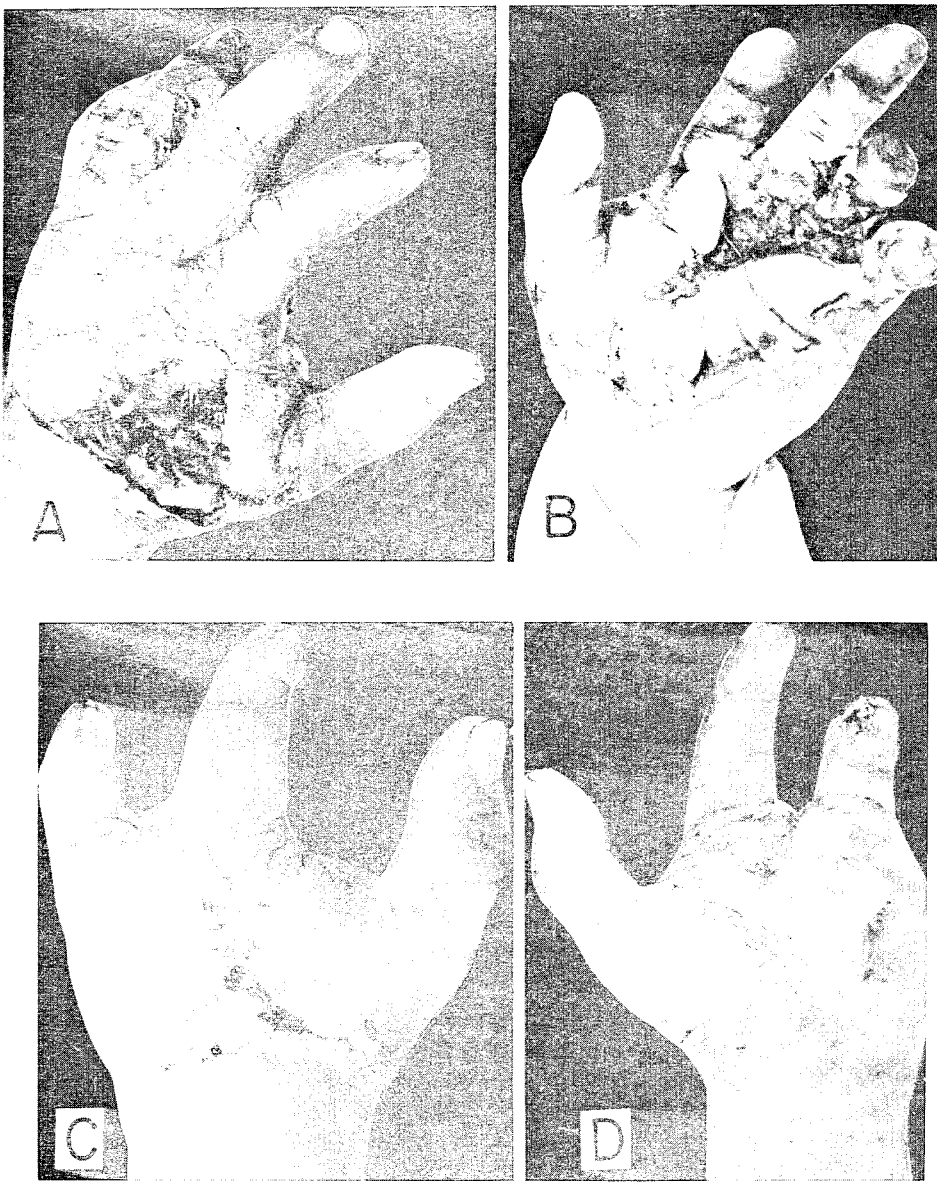



*Figure 56. Severe perforating shell fragment wound of left hand, which resulted in gangrene of middle and ring fingers. A and B. Appearance of hand just before secondary repair. C and D. Appearance of hand after amputation of gangrenous fingers and closure of dorsal and palmar wounds. This case is an illustration of the difficulty of obtaining prompt and satisfactory healing in severely torn and traumatized hands, the soft parts of which do not heal as kindly as do other areas of the body in which vascular supply is better.*

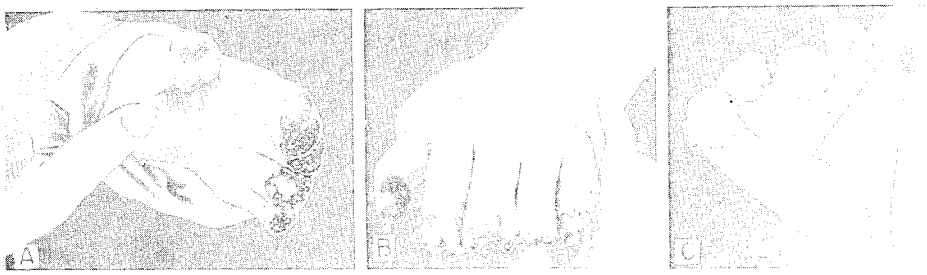



*Figure 57. Traumatic amputation of tips of all fingers on left hand. A and B. Appearance of hand just before secondary closure. C. Appearance of hand after split thickness grafts (skin dressings) have been applied to fingertips, to conserve length of all digits.*

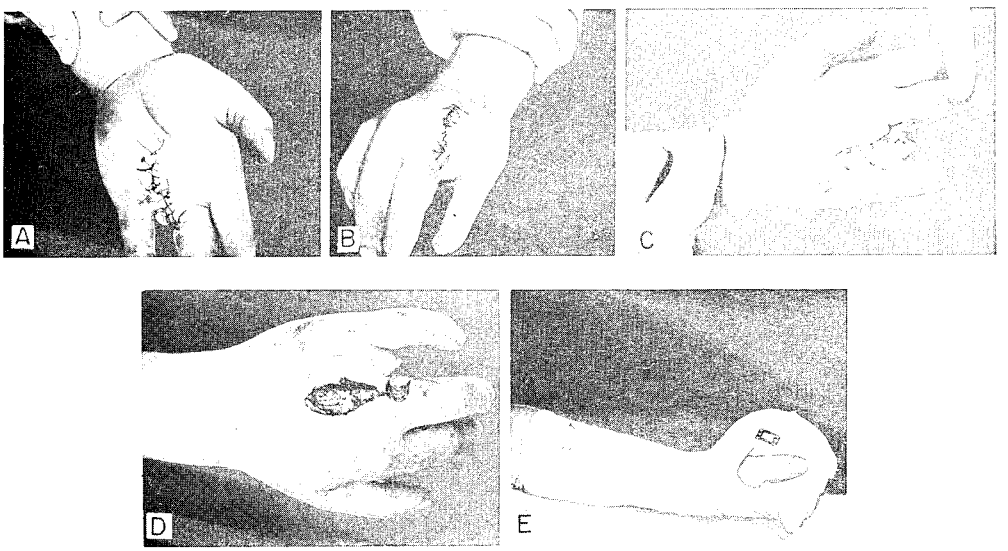



*Figure 58. Perforting shell fragment wound of left hand, with compound fracture of proximal phalanx and subsequent gangrene of ring finger. A and B. Appearance of hand just before secondary closure. C and D. Appearance of hand after simple closure of wound, with absence of undue tension. E. Hand on universal splint, with pressure dressing in place. Note position of function, with thumb free.*

portion to become well demarcated, so that as much length as possible could be conserved when amputation was done. Closure was a staged procedure.

*Technical Considerations.* Several technical considerations were important. Closure of amputations through joints, which had left exposed

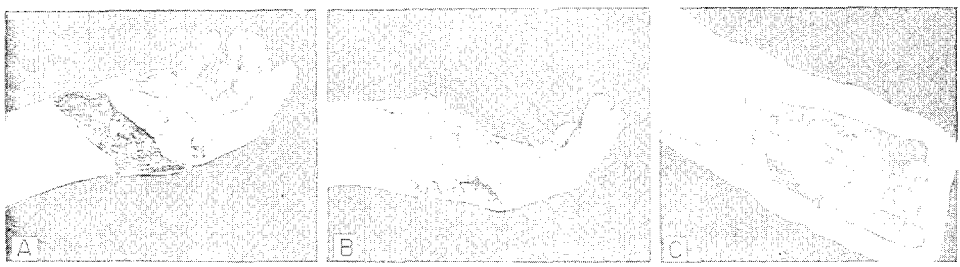


*Figure 59. Crippling shell fragment injury of right hand with amputation of thumb and severe loss of tissue across wrist. A. Appearance of hand just before secondary closure. B. Appearance of hand after closure by suture and skin graft. C. Appearance of hand 10 days after secondary repair.*



*Figure 60. Traumatic amputation of the left index finger by shell fragment. A. Appearance of hand just before secondary repair. B. Appearance of hand 10 days later, after use of volar flap. Note irregularity of stump. C. Appearance of hand 4 weeks later. Note that stump is now molding into satisfactory shape. This case illustrates the importance of salvaging and preserving all viable tissue on the hand, on which the soft parts are too scanty to permit radical revision and resection.*

cartilage, were not tampered with since the initial results were usually so satisfactory. When length had to be conserved it was often possible to draw some areolar tissue from the adjacent volar surface over the bone, providing a bed for the free graft to be applied (Fig. 57). Another means of conserving length was the use of a pedicle flap from the abdominal wall. This was an excellent technique to which the thumb adapts itself well.

It was not the practice to suture the flexor and extensor tendons over the end when an amputation stump was closed. This technique altered the tendon and muscle balance and often resulted in limitation of motion. It was usual to identify the digital nerves before secondary closure, to see that they were not within the area of closure or were not in such a position that they would be caught in the scar. Whenever this complication seemed likely to develop, 2 to 3 mm. of nerve were removed to prevent it.

In the closure of an amputation wound it was imperative to avoid tension. Unless this precaution was observed, poor coverage, delayed healing, and

necrosis almost invariably followed. The result was a tight, tender stump, in which pain prevented satisfactory function.

Although traction was often applied to amputation stumps of digits, this was not a wise plan. The deep attachment of the skin to the fascia made the palmar skin unsuitable traction to cover the end of the stump, and the use of it seemed to increase maceration.

*Sequelae.* Patients with old, healed, painful, stiff amputations of the fingers furnished troublesome problems. Many who had been assigned to duty, usually in limited categories, proved unable to do the work.

Examination would reveal a firm stump with a satisfactory soft tissue covering, but with painful neuromas within the scar which kept the patient from using his hand. Sometimes the scar was thin, bluish, tender, drawn tightly over the end of the bone, and likely to break down on the slightest trauma. Sometimes, too, a neuropsychogenic factor was evident.

A few patients with painful stumps were submitted to reamputation, alcohol injections or procaine hydrochloride blocks with unremarkable results. In some cases, if sufficient soft tissue covered the stump, exploration was carried out, the digital nerve was identified, and the neuroma was excised back to soft, fatty tissue, where it would be well away from the scar. In those cases in which the bone was covered with thin scar, complete revision of the amputation was indicated. When reamputation was required for any reason, the best practice was to ignore all so-called levels and remove only enough bone to permit healing to occur.

*Incidence.* Incidence of amputations of the hands or fingers is not of great concern for there were so many variables involved. In one series of 426 patients sent to the Zone of Interior because of major amputations there were only 49 with complete loss of the hand at the wrist and of these all but 2 were the result of battle injuries.

In another study 253 patients were sent to the Zone of Interior because of amputations of the fingers alone. Site of amputation is shown in Table 5. There was no great difference in occurrence of multiple amputations, for the incidence was 35.3 percent in the battle injuries compared to 31.0 percent in the nonbattle.

TABLE 5. BATTLE- AND NONBATTLE-INCURRED AMPUTATIONS BY SITE IN 253 PATIENTS EVACUATED TO THE ZONE OF INTERIOR

| Amputations | Total | | Thumb | | Index | | Middle | | Ring | | Little | | Multiple | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent |
| Battle | 182 | 71.9 | 22 | 12.1 | 29 | 15.9 | 23 | 12.6 | 17 | 9.3 | 27 | 14.8 | 64 | 35.3 |
| Nonbattle | 71 | 28.1 | 4 | 5.6 | 14 | 19.7 | 20 | 28.2 | 5 | 7.0 | 6 | 8.5 | 22 | 31.0 |

Recorded on the boards of the general hospital, the common complaints of these patients with amputations of the fingers were weakness, stiffness, or pain on using the hand. There were 9 patients of the group who had previously been assigned to limited duty but having failed at this had to be sent home because of the disabling amputation. An additional diagnosis of a neuropsychiatric condition was found in 1.6 percent of the battle casualty amputees and 11.2 percent in the nonbattle injury amputees. The thumb was amputated in 22 patients, 12.1 percent of the battle casualty amputees compared to 4 patients or 5.6 percent of the nonbattle injury amputees.

In a further study of 320 injuries involving only the hand, admitted to the 6th General Hospital,[22] the incidence of single or multiple, complete or partial amputations as a result of fractures totaled 62. Distribution by site is shown in Table 6.

TABLE 6. DISTRIBUTION OF 62 AMPUTATIONS FOR FRACTURES OF THE HAND AT 6TH GENERAL HOSPITAL

| Bones fractured | One finger | Two fingers | Three fingers | Four fingers | Thumb | Total |
|---|---|---|---|---|---|---|
| Phalanges | 41 | 4 | 2 | 0 | 4 | 51 |
| Metacarpals | 4 | 2 | 1 | 1 | 2 | 10 |
| Carpals | 0 | 0 | 0 | 0 | 1 | 1 |
| Total | 45 | 6 | 3 | 1 | 7 | 62 |

## BURNS

There were usually a large number of patients with burns of the hand on the hand service or on other wards of the base hospitals. The burns were sometimes accidental, resulting from gasoline or steam, and sometimes battle-incurred, from phosphorus shells or burning equipment. In the last 9 months of operation at the 12th General Hospital, 94 patients were admitted with burns of the hand, the majority of which were associated with burns of other parts of the body. Of the 94 injuries, 63 were accidental and the remaining 31 battle-incurred, a ratio of 2:1. The hands were usually involved in burns of other parts of the body because the patients had tried to beat out the flames or had used the hands to protect their faces from flames, smoke, or fumes.

### Factors Influencing End Results

The end results in burns of the hand depended upon three factors: the depth of the burn, the rapidity of healing, and the presence of infection.

[22] See footnote 10, p. 95.

*Depth.* The palmar surface of the hand was less frequently involved than the dorsal, where severe injuries were common because the thin dorsal skin was quickly burned away exposing the extensor tendons and interphalangeal joints. When the extensor tendons had been destroyed, they were replaced by dense scar tissue. If these tendons were exposed, it was sometimes possible to make a graft grow over those which were not infected or had not lost their normal color and luster and become completely dry. Tendons which had become dry and necrotic were useless and were removed when the slough was removed. It was futile to attempt to salvage structures in this condition. It might be possible later after a pedicle flap had been placed over the burned site to graft new tendons, but this was a reconstructive procedure for Zone of Interior hospitals, not one for overseas theaters.

If the burn were severe enough to expose or damage the small joints of the hand, it inevitably followed that motion in those joints could not be regained. The same was true if the small muscles of the thenar or hypothenar areas were burned; they had lost their function for all time.

*Rapidity of Healing.* The longer the raw wound was left unhealed, the deeper was the ultimate scarring and the more extensive the binding of tendons, small muscles, and joints. The longer the wound was left open, the greater the hazard of infection. To wait for spontaneous covering when all elements of the skin were lost invariably resulted in scar tissue epithelium which would not tolerate use or motion and invariably had to be removed before a successful result could be expected.

Scarring of this sort was particularly frequent in burns of the dorsum, which were ordinarily classified and treated as if they were second-degree burns. In these injuries there were usually sufficient remaining epithelial elements to permit spontaneous—albeit very slow—healing. A great deal of fibrosis occurred, and the dorsum of the hand was eventually covered with thin, rough, inelastic dry skin, so that active flexion of the wrist and fingers was limited and forced flexion caused cracks in the integument across the joint. This skin broke down with minimal trauma, and, if allowed to continue uncorrected, a keloid type of scarring was likely to occur. The only possible treatment was removal of the entire skin covering, with replacement by a thick split thickness graft.

The chief objective of the surgeon who handled burned patients was therefore to secure healing as early as possible by the simplest method possible, which, in the early phase of the injury, meant split thickness skin grafts. Plastic procedures might be necessary later but were not performed in overseas theaters. The more rapidly a wound could be grafted and healed, the earlier could active motion be instituted and the better the end results were likely to be.

*Infection.* Infection not only prevented healing but also deepened and widened whatever scarring was present and brought adjacent structures into the original necrotic process. Precautions to prevent infection from the time of initial care and during all subsequent dressings was repaid many times over

in the degree of healing and function secured. If infection occurred, it usually required a long time to clear it up, and the end results were almost always disappointing.

## Management

The results in burns of the hand, which during the North African campaign had originally not been very satisfactory, began to show a remarkable improvement when a routine treatment was adopted consisting of cleansing of the parts, minimal debridement, and immobilization with a pressure dressing and splint. It was the feeling of some surgeons, though it was not general, that better results were obtained if blebs were opened when initial care was given, this on the ground that if these were allowed to remain maceration was more likely to occur and healing seemed somewhat delayed especially if the palm or the digits were involved.

Because the hand normally exhibits a strong tendency to maceration, dry, fine-mesh gauze was employed rather than vaseline gauze or other greasy dressings. Each digit was dressed individually, and gauze was placed in the web spaces. A large, resilient pressure dressing was applied to control edema, since, if it were allowed to persist, deep fibrosis could be expected to occur. The hand was placed on a splint in the position of function exactly as in fractures, and great care was taken to see that the proper position was maintained.

Fractures were not often associated with burns of the hand, but wounds by shell fragments were. They were treated by debridement and the removal of foreign bodies, under anesthesia. The burned areas were then submitted to the routine treatment for burns.

In burns severe enough to cause death of digits, the policy of management was conservative. Amputation was delayed as long as possible, while the remaining parts of the hand were treated by excision of the slough, and skin grafting. When complete demarcation had occurred, the gangrenous part of the digit was removed and the stump closed after an interval of 3 to 4 days. As much length as possible was preserved in each digit.

Burns of other parts of the body associated with burns of the hand required treatment with plasma, later the administration of whole blood in adequate amounts, a diet high in protein and vitamins, and other measures usually employed.

Dressings were kept snugly in place for 12 to 14 days. It was sometimes possible during this period to estimate the severity of the burn: If the dressings were dry and loose, it could be assumed that the burn was superficial, while if they were firm and moist, it was usually deep.

If the burns were thought to be superficial, the dressings could safely be removed on the ward. If healing was not complete, only small and superficial unhealed areas usually remained. If the dressings were reapplied, healing usually occurred within 7 to 10 days.

If the burn was thought to be deep, or if there was any doubt about its depth, the dressings were removed in the operating room 12 to 14 days after the injury. The patient was anesthetized and any slough which was present was removed by sharp dissection down to bleeding tissues. It was sometimes possible to excise the slough earlier than the 12th or 14th day after injury, but the general experience was that this interval was necessary to allow full demarcation between the superficial and deeper burned tissues. If it were certain that the entire slough had been removed, the raw area could be grafted at once. As a rule, it was not possible to establish this fact positively and it was the practice to dress the wounds with dry, fine-mesh gauze, apply a pressure dressing over a molded splint, and reexamine the wound in the operating room in another 3 or 4 days. It was sometimes necessary to remove additional tissue at this time, but in most instances the wound was then in satisfactory condition for skin grafting.

The site of the donor area was carefully planned, because often other parts of the body had to be grafted either at the same time or at a later staged procedure. The graft to the hand was always large enough to cover the burned area completely. Pinch grafts (postage stamp grafts) were not used on the hand, because complete coverage was necessary to obtain early healing and full function. The skin was not sutured into place, simply spread out and held in position by a pressure dressing and splint (Fig. 61).




*Figure 61. Phosphorus burn of left hand, involving dorsum of thumb and volar aspect of wrist. A. Appearance of hand 14 days after injury. At this time granulating areas were quickly prepared for skin grafting. B. Split thickness skin grafts in place over dorsum of thumb and across wrist. C. Appearance of hand 8 days after skin grafting. Although this was not an extensive burn, if it had not been closed as rapidly as possible, undue scarring and secondary infection might have ensued, with attendant loss of function.*

When grafted areas were dressed on the ward 4 or 5 days after operation, all excess or overlapping skin was cut away. Unhealed areas were regrafted at once. The wound was dressed as initially, that is, with dry, fine-mesh gauze, a pressure dressing, and a splint. Subsequent dressings were done every 3 or 4 days, depending upon the condition of the wound. In most cases it was possible, by the routine described, to have all burned areas grafted and closed within 3 weeks or less from the time of injury.

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At each successive dressing the size of the splint was reduced to permit motion of the healed parts in correlation with the degree of healing. Within 10 to 12 days after the area had been grafted healing was usually sufficiently advanced to permit active motion. It was imperative, however, that patients be carefully instructed in the use of their hands. Mere sawing back and forth at the metacarpophalangeal joints was not enough. It was necessary that the whole hand and the small joints be used in a full and complete range of motion. The patient was encouraged to feed himself, brush his teeth, and take care of all of his own needs. Increasing use of the injured hand provided a great stimulus to morale. A patient with both hands burned was always very proud when he was able to use them and to begin to care for himself again.

Reports in the British literature, together with the poor results originally achieved in burns of the hands in American troops, led some surgeons in the theater to attempt to gain immediate motion of the joints in third-degree burns by omitting splints and by using soaks. At one hospital in which early motion was encouraged, burned hands were dressed daily and soaked frequently. Two patients submitted to this type of treatment had exposed dorsal tendons, while another presented a necrotic capsule on the dorsum of the hand at the level of the metacarpophalangeal joint of the thumb. It seemed completely illogical to force a patient with this sort of injury to move his fingers through a complete range of motion. Motion in the presence of granulating wounds also seemed illogical as it tended to increase the depth of the wound, and manipulation of the small joints of the hand under anesthesia obviously had the same effect. These practices were discouraged, and all attention was devoted to securing complete healing in the shortest possible period of time. After it had been attained, active motion was permitted and encouraged under careful supervision.

When the framework of repair had been broken down by early motion, the young granulating wound became firm and irregular, with heaped-up granulation tissue surrounded by a thin areola of scarred epithelium. Excision of the scar tissue and skin grafting were eventually necessary, but the results were never as satisfactory as when skin grafting was undertaken at the optimum time.

After healing had been accomplished, the mobility of the joints could be further supplemented by the use of elastic splints of various kinds, devised to encourage flexion of the small joints while permitting extension at the same time. This form of traction exerted a steady, resilient, healthy pull upon the smaller joints and upon their capsules. The splint was worn at night but was used only at intervals during the day. Its use was found to be more effective than the manipulation of the small joints under anesthesia.

## Sequelae

The deeper and the more extensive the burn, the greater was the tendency, at least in certain cases, for late swelling to be present, even after

healing. It was especially frequent in poorly managed cases (Fig. 62). Active, vigorous use of the hand neither increased nor decreased it. With the passage of time, and with persistent careful use, the swelling was likely to subside spontaneously. In the meantime, the hand was constantly kept elevated, any treatment or activity which involved heat and dependency was considered contraindicated, and movement was continued, but with proper precautions.

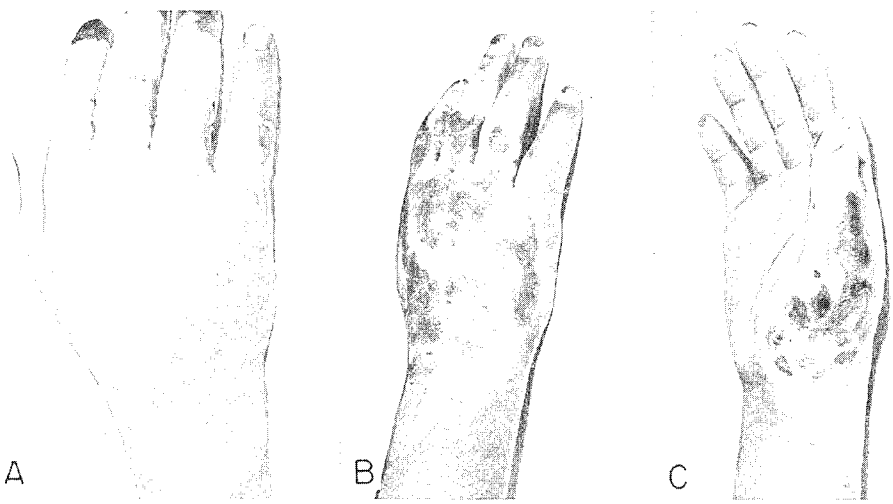



*Figure 62. Infected phosphorus burn of dorsum of right hand, showing typical results of neglect, especially failure to close wound at earliest possible moment. A. Appearance of hand when skin grafting was done 32 days after injury. Note sites of scar tissue epithelization. B and C. Appearance of healed hand 1 month after closure. Persistent extreme swelling resulted from failure to obtain closure of this wound at an earlier date. The delay permitted granulation tissue to become infected and edema to become fixed, with the usual sequelae of a doughy, stiff hand.*

In certain moderately severe burns, healing frequently occurred after a complete cast-like slough of the nails and the skin of the tips of the fingers had separated. The residual red, thin skin tolerated use very poorly.

## FROSTBITE

In frostbite, as in burns, the pathologic changes which had occurred did not become fully evident in most cases until many hours after contact with cold. The history of the origin of the symptoms was important; in its absence a mistaken diagnosis could readily be made. The Air Corps personnel were most often affected by this type of injury which was sustained at high altitudes, with temperatures as low as −20 degrees centigrade. Causes

were chiefly failure of protective clothing, carelessness in removal of gloves, and the effect of windblast on the hands. The thumb was seldom involved.

In mild frostbite cases the patient might complain only of numbness, tingling, and stiffness of the fingers. The hands were normal in appearance or only slightly pale. In severe cases the fingers were stiff and insensitive and had a waxy appearance. Patients with frostbite had more pain in the early stages of injury than patients with burns. As time passed, swelling and stiffness became progressively more marked, and the dorsum of the fingers became covered with blebs (Fig. 63) filled with strawberry-colored or blood-tinged fluid. In milder cases a cast-like slough developed at the tips of the digits and nails. In severer cases dry gangrene developed. It was impossible to determine when the patient was first seen whether the injury was mild or severe or what its final depth or extent would be.

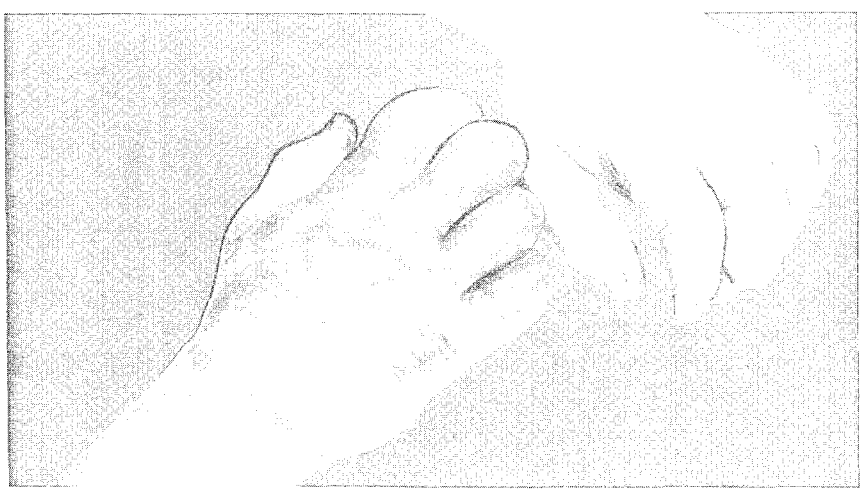


*Figure 63. Moderate frostbite of both hands 24 hours after injury. Note large blebs. These injuries were treated as if they had been fresh burns, with cleanly care and immobilization. Healing occurred without any loss of skin. Had loss of skin occurred, it could have been treated, after 10 to 12 days, as a burn would have been treated, by removal of any sequestra of the soft parts and early coverage with a skin graft.*

Cold injuries of the hands were treated by the same methods as were applied in burns, by cleansing, the application of a resilient pressure dressing and splint, and elevation of the hand in the position of function. The earlier the treatment was instituted, the less was the swelling. Pain was usually relieved by elevation of the part, and opiates were not required. The dressing was kept snugly in place for 12 to 14 days. Then the injured hand was inspected and its status evaluated. Mummified, gangrenous portions were permitted to become demarcated before they were removed. Even when gangrene was not

present, the skin was likely to be thin and red for several weeks and a change of position or of temperature might produce throbbing pain. Paresthesias were also frequent. Late swelling was a common complication, and, as in burns, was best treated promptly, since thickening of the tissues quickly became permanent. Patients with sensitive, swollen hands following frostbite could only occasionally be returned to duty.

Late swelling of the hand was occasionally accompanied by sweating and redness of the parts. Although the routine just described was employed in this group of patients, possible psychogenic factors had to be taken into consideration. Procaine hydrochloride injection of the cervical sympathetic nerves was occasionally practiced and was sometimes of transient benefit, but was not of sufficient value to be encouraged as a routine because of the risk of increasing or fixing the importance of the condition in the mind of the patient.

## SEQUELAE OF HAND INJURIES

Attention has been called elsewhere to the initial swelling following hand injuries and to the importance of measures to reduce it. In some cases it was inclined to be persistent and to limit function. This occurred most often after crushing injuries, burns and infections, but the persistence and degree of the swelling were not necessarily correlated with either the type of injury or its severity. The therapeutic routine in such a case was to begin treatment with a short period of absolute rest with the patient in bed and the hand in a splint and continuously elevated. After a few days, graduated motion was begun. Careful supervision was required, for while it was important that the patient move his hand, it was equally important that he should not move it too vigorously; too little motion permitted the stiffness to become permanent, but too vigorous motion perpetuated and aggravated the swelling. Although treatment was tedious, the condition responded as a rule to time, encouragement, and guarded increase of movement.

Causalgia was too infrequent to be a serious problem to the surgeons. In the patients affected, the wounds were usually old and of varying degrees of severity. The color of the hand was altered, sometimes being red and sometimes blanched. The skin was shiny and smooth. The patient usually tried to keep the hand protected in some manner, frequently by means of a moist bandage. The fingers could be moved slightly by the examiner, but the patient himself moved them gingerly because of fear of causing pain. Inquiry into the past history usually produced a story of delayed healing and of the trial of many kinds of treatment, from which only temporary or incomplete relief was secured. The location of the pain was usually such that actual nerve involvement of some degree always seemed possible, though detailed examination often failed to identify completely the nerve which might be involved. As a rule the sites

of the most exquisite tenderness were chiefly confined to the palmar area of the median nerve.

Treatment consisted of exploration of the involved nerve, sympathetic block, and psychotherapy.

Perforating wounds of the palm frequently healed with small scars in which neuromas were incorporated (Fig. 64). Severe pain always occurred when the part was moved or when anything was grasped. Patients with neuromas in the palm were generally benefited by secondary surgery and could usually be returned to duty promptly.

The operation itself was not difficult because the common digital nerves in the palm can readily be identified and lend themselves well to suturing. The technique was simple: In a bloodless field the nerve was dissected distally and proximally back to normal tissue and down to the scar, so that the extent of the damage could be determined. Digital nerves and tendons held in deep scar tissue needed only to be freed. The site of damage was protected by a fat graft or by the placing of adjacent areolar tissue around the tendon to prevent a recurrence of the neuroma.

## INFECTIONS

The incidence of infection following battle-incurred injuries was gratifyingly small and its management furnished no particular problems. On the

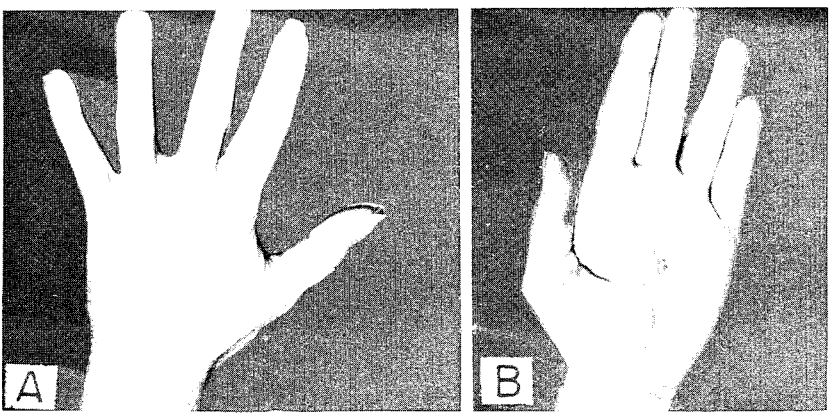



*Figure 64. Typical small perforating wound of left palm, without bone damage. A. Dorsal aspect. B. Volar aspect. This patient's experience was unfortunately common: The wound healed rapidly but he could not be returned to duty because of a painful neuroma of the common digital nerve supplying the adjacent lateral aspects of the third and fourth digits. He was unable to grasp objects or use his hand in a normal manner and was therefore unfitted for combat duty. Failure by the surgeon to recognize injuries to deeper structures was often the reason why a soldier with a minor injury of the hand could not return to full duty.*

hand services, however, there was a constant influx of patients with infections the majority of which were similar in all respects to those seen in civilian practice.

Management of these infections, as was pointed out to the Theater Surgical Consultant in the survey made early in 1945, was at that time not at all satisfactory. Incisions were made too early, before localization had occurred; they were not well placed; they were not large enough to accomplish drainage. Sometimes they had been made without anesthesia, or worse, had been made with local infiltration. Midline incisions were frequent. Through-and-through drains were commonly used, and some of them were reinserted daily. Immobilization for the infected part was seldom provided.

With these methods of treatment it was small wonder that there was much delay in the return to duty of patients with hand infections because of inadequate drainage, extension of infection, the development of osteomyelitis, and similar causes. Many cases of osteomyelitis followed bone felons and most of them could easily have been avoided. Usually either a small, inadequate midline or a fishmouth incision had been made, with the result that necrosis of bone occurred and the patient was left with a deformed fingertip and an adherent scar. Late swelling following infection was usually the result of an incorrect diagnosis, an improperly placed incision, or the retention of necrotic material deep within the hand.

Infections which were diagnosed and treated properly were seldom followed by impairment of function. Ideally, as in civilian practice, every effort was made to diagnose early and accurately and to treat infections with ultimate function in mind. In the early, acute, spreading phase of the process before localization had occurred, treatment was limited to the use of large, sterile, warm, moist dressings and to immobilization; the hand was elevated, splinted in the position of function, and kept at rest, to encourage localization. Penicillin and the sulfonamides were used parenterally. Whether they influenced established infections is doubtful but they were thought to shorten the course of early spreading infections.

As soon as fluctuation was evident, but never before localization had occurred, the lesion was incised under general anesthesia with a blood pressure cuff in place to provide a bloodless field. The incision was carefully placed so that drainage would be adequate. Midline incisions were avoided and deeper structures, such as the nerves and blood vessels, were identified and protected from injury. Hemostasis was accurate. A small vaseline gauze drain was inserted into the wound to hold the edges apart. It was so placed that it did not plug the wound and no accumulation of pus could occur behind it. At the conclusion of the operation the hand was splinted, and sterile, warm, moist dressings were applied.

The hand was kept well elevated at all times during the postoperative period. The dressing was moistened at regular intervals, enough sterile solu-

tion being applied to encourage drainage but not enough to flood the dressing and encourage maceration.

The drain was removed at the end of 48 hours and was never reinserted or replaced. Moist dressings were replaced 3 or 4 days after operation by dry ones. Motion was permitted only after the wound was well healed, experience having shown that earlier motion was likely to reactivate the infection and cause further damage.

## SPECIAL LESIONS

*Felons.* These were common and unfortunately were often not recognized until the patient had experienced severe pain and throbbing. As early as possible they were drained by a lateral incision, with division of all the fibers transversely so that the entire distal closed space of the finger was opened.

*Paronychias.* This condition was treated by making two lateral incisions on the dorsum of the finger to expose the bed of the nail, the proximal third of which was removed. The eponychium was elevated and was kept in this position by vaseline gauze until drainage had been accomplished; it was then permitted to fall back into place.

*Collar-Button or Web-Space Infections.* These infections frequently followed small puncture wounds or originated under calluses, and were often associated with swelling out of proportion to the size of the lesion. As usual, however, the swelling was most often the result of the lax areolar tissue in this area and not necessarily due to the presence of pus on the dorsum of the hand. The palmar concavity was lost only when there was a deeper infection below the palmar fascia. In collar-button infections special precautions were taken to make sure that each of the compartments of the lesion was drained. Deep palmar space infections and tendon sheath infections, which were not common, were drained by the method suggested by Kanavel.[23]

*Lymphangitis.* Lymphangitis which followed subcuticular and subcutaneous infections of the hand was treated by immobilization, elevation of the extremity, and the application of large, sterile, moist dressings extending to the axillary space. No surgery was undertaken unless definite localization occurred. In the few cases in which incision and drainage proved necessary, the blood pressure cuff was not used at operation because of the possibility of dissemination of the infection through the lymphatic channels in the upper arm.

*Osteomyelitis.* Whether osteomyelitis developed in a distal phalanx of a finger or elsewhere on the hand, it was likely to drain over a long period of time and adequate drainage of the soft parts, with immobilization, had to be provided until sequestration had occurred. Curettage of the bone was not practiced, nor was amputation considered. When the sequestrum could be removed healing was prompt, and it was often surprising to see how much bone had

[23] Kanavel, Allen B.: Infections of the Hand. 1st ed. Philadelphia, Lea & Febiger, 1916.

survived. Unfortunately, it was also often disappointing to observe the residual deformity which followed the deep infection. Roentgenograms were not very useful in osteomyelitis of the bones of the hand because of the decalcification usually present.

## MISCELLANEOUS CONDITIONS

Miscellaneous conditions of the hand observed in the various hospitals for the most part did not differ greatly from those observed in civilian practice. They included Dupuytren's contracture, trigger finger, rupture of the extensor tendon of the thumb after Colles' fracture, web fingers, baseball finger, and tumors of the hand, including bone tumors, enchondroma, vascular tumors, implantation cysts, and ganglions.

## PSYCHOGENIC FACTORS

One of the serious problems arising from injuries of the hand was provided by a small but extremely troublesome group of patients who for the most part had sustained relatively mild injuries but had complaints and symptoms out of all proportion to the evident extent of the pathologic process. It was difficult to rehabilitate these for return to service and, when they had been returned, difficult to keep them performing the duties to which assigned.

Unfortunately, there was no way of predicting which patients would fall into this group. It was not until the wound was healed and function was about to be resumed that they revealed themselves. Then they complained steadily of stiffness, severe localized pain or inability to use the extremity because of deep pain extending from the hand to the shoulder. Obviously, patients who failed to use their injured hands as directed ran the risk of doing further harm to themselves by allowing atrophy of disuse and prolonged fixation of small joints. It was explained to them repeatedly that they were placing the function of their hands in jeopardy but they did not seem to realize the danger, nor did the warnings strike a responsive note. They seemed purposefully to refuse to use their hands for fear that if they did they might be required to return to duty. Consciously or unconsciously they must have realized that as long as they did not use their hands they could not be returned to duty. Many used their apparent incapacity as an excuse to remain in the hospital for long periods of time, and then when ready for discharge invented complaints involving the teeth, the eyes, the feet or the gastrointestinal tract, which served the same purpose.

A strikingly large proportion of those in this group had injuries which were accidentally-incurred or occasionally self-inflicted, but in only a few instances were additional injuries inflicted by the patients themselves in order to prolong their hospitalization. It was noticeable that these men did not

speak of their units with pride nor did they express the desire so often heard on any large ward to return to their outfits. It was impossible not to feel that they were accentuating whatever disabilities they might really have. It was not the general opinion that the proportion of patients in this category was any larger or any smaller than would have been observed in a comparable group of persons eligible for industrial compensation in civilian life, though there are no statistics to corroborate this impression.

## Classification

The cases in this group fell into three categories, hysteria, anxiety states, and malingering.

*Hysteria.* These patients were interesting, but comprised only a small percent of the total and were likely to have been through several installations, including the replacement depot. Sometimes they had tried full duty after being discharged from the hospital in which originally treated. As a general rule, their injuries were not extraordinarily severe. Some complained of glove anesthesia following minor wounds of the hand, forearm, or arm. Some showed complete loss of function of the hand or bizarre muscular or nerve patterns of dysfunction entirely incompatible with the pathologic process present. They were likely to state that they could not move certain digits or that anesthesia of a digit was complete, although the site and location of the injury made it quite clear that the tendons or the common digital nerves which they implicated in their complaints could not possibly have been involved. Repeated examinations usually produced the same complaints and the same findings but occasionally variations made it important that accurate notes be kept so that the results of one examination could be compared with those of another.

*Anxiety States.* Patients suffering from anxiety states had usually been wounded recently though in some instances the manifestations of which they complained came on spontaneously in the absence of any injury. They were quiet and withdrawn and seldom participated in the activities of the ward. They spent much of their time lying on their beds. Their hands were usually warm and moist, had moderate tremors, and often seemed to deteriorate while they were on the ward, particularly after motion had been started. Such patients frequently complained of vague anesthesia with loss of motion, but sometimes the only complaint was stiffness of the extremity.

These patients did not resent being shown how to improve the function of the hand, though their acceptance of instruction was vague, disinterested, and passive. Sometimes function slowly improved, but as it did, and as the time approached for return to duty, they frequently showed an increase in tremors, slept badly, and began to complain of pain, discomfort and other symptoms elsewhere. The late transference of symptoms might be to any system of the body.

The following case report is typical of the patients in this group:

*Case 7.* A 27-year-old technical sergeant in the infantry, who had had a total of 4½ years of service, including 9 months overseas and 6 months in combat, was seen 22 February 1945. He complained of numbness in the left little finger. About a week later the ring finger became involved and within a short time all the fingers, the whole hand, and the wrist on the left side were affected. On 23 March when the patient was admitted to the hospital because of inability to use the hand, the upper arm could be moved freely within the normal range of motion but he could not flex his hand or extend the fingers or the wrist. There was no history of local trauma or preceding illness Inquiry into the patient's previous history revealed that 7 years earlier the left foot had become weak and a toe drop had developed which had persisted for about 7 months. A slight weakness of the foot, according to the patient, was still present.

Examination revealed that the upper left arm was apparently entirely normal. The fingers and the entire left hand and wrist seemed to be completely paralyzed, all of the flexors and extensors being involved. Sensation was about equal throughout the extremity. At a second examination, 9 April, glove anesthesia was present from the lower third of the left forearm through the tips of the fingers. The patient could not move the fingers or close the hand.

The response to faradism and to psychotherapy was excellent and the man eventually had full use of the hand and could be discharged from the hospital to temporary duty. When psychotherapy was first begun he denied anxiety but as his functional paralysis was resolved, considerable anxiety was liberated. His attitude was good and his morale excellent, as it had been throughout. He admitted that for some time before the development of the difficulty he had become increasingly depressed by his responsibilities as platoon sergeant and that he had finally lost all confidence in himself.

The final diagnosis was psychoneurosis, anxiety state, with conversion symptoms. The case was regarded as one of genuine conversion in a soldier with an anxiety reaction whose anxiety over future combat was released when conversion cleared up on psychotherapy. It was thought that after a temporary period of limited service this man could probably be reclaimed for unlimited duty. The end result is not known as the case was not followed up.

*Malingering.* The largest number of patients with hand injuries who presented psychogenic manifestations fell into the category of malingering. In most instances they had suffered recent injuries. The typical patient, after complete healing of the wound and just when he should have been showing a gradually increasing range of motion, claimed that he could not even move the digits. Under passive motion it was possible to obtain an almost complete range of motion, but actively only 15 to 20 degrees of flexion seemed possible. When the digits were manipulated, the joints felt rubbery and as if motion were being carried out against some resisting force. The patient held the wrist flexed while trying to move the digits, a position which places the flexor

group at a disadvantage and increases the mechanical advantage of the extensor muscles. Examination was likely to reveal either that the flexor muscles of the forearm were not contracted or if they were the extensor muscles were also taut and firm.

When a patient in this category was shown the difference in the function of the muscles of the two extremities he was likely to become garrulous and indignant and to insist that he had been trying to obtain motion but that the digits, in spite of the absence of pain and swelling, simply failed to move. He was also likely to claim that he simply could not understand the situation, since he had been trying as hard as or harder than any other patient to move his fingers. He created in everyone who heard him the impression that he was justifying his position by argument.

The following is a case in point:

*Case 8.* A 23-year-old infantry staff sergeant was first wounded in May 1944, in the right shoulder. In September of the same year he received a wound of the right hand and was burned about the face. Following the second injury he developed a flexion contracture of the right middle finger which incapacitated him for further combat duty. He had been evacuated twice because of this deformity, each time passing through several installations. On his third evacuation he was sent directly from a clearing company to a general hospital. Examination at this time revealed a flexion deformity of the right middle finger, for which no organic basis could be found. The patient also complained of "blackout of vision" of the left eye.

This sergeant had been in the service for 2½ years, 17 months of which he had spent overseas. He had had 6 months of combat, during which he had apparently displayed great courage and skill. He had been recommended for the Distinguished Service Cross and while he was at the 12th General Hospital he was awarded the Silver Star for valor.

After neuropsychiatric consultation he was transferred from the surgical to the neuropsychiatric section. Here he was contented and cooperative but he continued to insist that he could not straighten out the middle finger himself in spite of the fact that it could be completely extended by gentle traction. He was hostile to the suggestion that the defect was functional and persisted in the flexion deformity even under intravenous sodium amytal narcosis; as much as 23 gm. of the drug was given. The persistence of eye symptoms required ophthalmologic study. Repeated examinations revealed positive tests for malingering.

Although the patient was extremely bitter about the treatment he was receiving when he had what he called "an obviously disabling" deformity, he was finally frankly confronted with the facts and was told that both the flexion deformity and the supposed loss of vision were the result of malingering. When he became threatening and belligerent he was told that his previous combat record and his Silver Star would not save him from a court-

martial. When he eventually quieted down, the finger promptly relaxed and with its relaxation his vision returned to 20/20 in the right eye and to 20/25 in the left eye. After he straightened the finger out he admitted a fear of returning to duty. He was put to work sweeping and mopping for several days and was then returned to full duty. During the 2 months' period of subsequent observation no relapse occurred.

This man's previous history revealed no evidence of neuropathic tendencies. He had gone through the fifth grade at school and in civilian life was an oilfield worker.

## Management

Certain prophylactic and therapeutic considerations were extremely important in the management of these patients:

1. Those who convalesced slowly and poorly after minor hand injuries always did better if they received continuity of care by the same surgeon, which was difficult to provide when the hospital load was heavy. Too often the men who did not respond to treatment were transferred from one installation to another until all continuity of treatment was lost. Only when the same surgeon continued to see them could their true condition be recognized and their status properly evaluated so that they could be returned to the appropriate type of duty.

2. Secondary surgery did not help most of them. Amputation of a stiff finger or a portion of the hand did not guarantee return to any sort of duty. Surgeons soon learned to be cautious about advising operations for patients who complained of vague, indefinite pains in scars or amputation stumps or of similar complaints. The results were seldom good in respect to either relief of pain or improvement of function. This was particularly true of men returned from replacement depots who had been placed in either the full or the limited category of duty and who had been returned because they could not carry out either. Many had legitimate complaints it is true, but many others did not, and in this group satisfactory results practically never followed secondary surgery.

3. Even in some of the resistant cases it was possible by repeated demonstrations to induce the patients to move their hands, but some few would not be convinced until something more dramatic was done. Faradic stimulation was of value and occasionally was repeated several times. The simple act of drawing a diagram of nerves or tendons on the skin of the forearm or hand and explaining, in the simplest possible language, the discrepancy between the actual injury and the patient's functional disability sometimes had good results.

4. It was unwise to ignore the patient or to tell him to forget his difficulties. The longer he continued in his current state of mind, the harder it became to change the pattern.

5. These patients needed constant encouragement and repeated explanations of their status. They could not be pushed into duty. Many of them believed that their hand injuries were severe enough to warrant their evacuation to the Zone of Interior and they resented the thought that they could be returned to any sort of overseas duty. They had to be led and guided throughout their convalescence.

6. As a rule these patients did not improve at all when turned over to the physical therapy department and it was soon learned that it was best to forego such treatment for them.

7. In a few cases it was necessary to consult the neuropsychiatrist and to resort to psychotherapy. Patients with anxiety states frequently required such assistance before they could be returned to any sort of duty. In this group, however, as in all others, the most generally effective treatment proved to be repeated statements of what the surgeons expected regarding the function of the injured hand.

8. The patients just discussed could seldom be returned to full duty. Their reaction during convalescence made that clear. They failed to progress as well as they should have in view of the injuries they had received, which often were not serious. They were inclined to protect and favor the injured hand and to treat it as if it were a fragile and delicate organ. Under the circumstances they were no assets to their organizations and experience proved that it was best to return them to limited duty.

## ADMINISTRATION

In base hospitals it was a decided advantage to concentrate all hand injuries on a single service whenever practicable. The correct treatment of this type of injury could be carried out only by a surgeon who could perform all the procedures necessary to promote healing and preserve and restore function. This required orthopedic and neurologic training, as well as training in plastic surgery, qualifications which the average surgeon did not possess and which could be put to most economical and efficient use only if patients were concentrated for treatment under men who did possess them.

Ward personnel played an important part in the management of hand injuries. Nursing care was difficult because the voluminous dressings made patients unable to care for themselves, particularly if both hands were injured. An intelligent and cooperative nurse working under the supervision of a competent and enthusiastic surgeon could so direct patients during their convalescence as to improve their morale and contribute to their functional recovery. Although physical therapy was used only on indications and not routinely, a close liaison was maintained between the personnel of the department and that of the hand service. The same was true of the hobby shop, whether it was con-

trolled by the Red Cross or by the physical therapy department. Hand patients made up a large proportion of the hobby shop's clients.

The technician of the brace shop was regarded as a member of the team which managed hand injuries since it frequently required a good deal of ingenuity on his part to contrive some of the splints needed.

## EQUIPMENT

Special equipment and supplies were used for all hand surgery. The arm board attached to the operating table was large enough to support the entire hand and arm without loss of stability. Small hemostats, needles, and retractors were provided; the surgeon who had to use large, unwieldly instruments instead of small, delicate ones began with a handicap. Irrigating sets were part of each surgical setup, irrigations being preferred to sponging, which further traumatized exposed nerves, tendons, and soft tissues. Knives and other equipment for skin grafting were prepared for every case, so that there would be no temptation on the part of the surgeon to use other less satisfactory methods of closure in difficult cases. A large supply of splints of various kinds was kept on hand, and a metal splint was sterilized before operation whenever it was believed that it would be useful.

## DISPOSITION

In the great majority of hand injuries it was possible to foretell with considerable accuracy at the time of the first examination what the disposition of the case would be. This information was conveyed to the patient at once. He was told the results expected from treatment and the type of duty to which he would be returned. If return to full duty was anticipated, he was told that prompt healing and complete return of function were expected, and was thus prepared psychologically for rapid return to his unit.

A large proportion of the patients observed were discharged from the hospital to duty of some type in the theater. Experience showed that the performance of these patients was often disappointing. Even when psychogenic factors were apparently lacking, soldiers with hand injuries frequently seemed unable to carry out the types of work expected of them.

There was often no relation between the size of the wound and the eventual function of the hand. Some of the smallest puncture wounds from knives or glass resulted in division of tendons and required evacuation of the patient to the Zone of Interior. The anatomic site of the injury, as well as its character, had much to do with the ultimate disposition of the case (Tables 7, 8, 9, and 10). Eighty-eight percent of the patients with phalangeal fractures and 55 percent of those with metacarpal fractures at the 6th General Hospital were returned either to combat or limited duty. Ninety-five percent of the patients at this hospital with soft tissue wounds alone returned to duty (Table 7).

When the injuries involved the bones, two factors influenced the disposition: Whether the fracture was simple or compound, and the portion of the hand in which it was located (Table 7). The more closely the fracture approached the wrist where so many important structures are concentrated, the greater was the disability and the less the likelihood that the soldier could remain even on limited duty in a theater of operations.

TABLE 7. PROPORTIONATE DISPOSITION ACCORDING TO TYPE OF INJURY OF CASUALTIES WITH HAND INJURIES AT THE 6TH GENERAL HOSPITAL

| Type of injury* | Cases | Full duty | Limited duty | Evacuation | Transfer to another hospital |
|---|---|---|---|---|---|
| Fractures: | | *Percent* | *Percent* | *Percent* | *Percent* |
| Carpus | 23 | 30 | 10 | 40 | 20 |
| Metacarpal | 74 | 37 | 18 | 37 | 8 |
| Phalanx | 132 | 57 | 31 | 5 | 7 |
| Soft tissue only | 84 | 82 | 13 | 2 | 3 |

* Seven traumatic amputations are not included.

TABLE 8. COMPARATIVE PROPORTIONATE DISTRIBUTION AND HOSPITALIZATION OF HAND INJURIES AND ALL INJURIES AT THE 6TH GENERAL HOSPITAL*

| Disposition | Hand injuries | | | All injuries | | |
|---|---|---|---|---|---|---|
| | Cases | Percent | Average hospital days | Cases | Percent | Average hospital days |
| Full duty | 176 | 55. 0 | 34 | 2, 659 | 52. 9 | 33 |
| Limited duty | 69 | 21. 5 | 58 | 777 | 15. 5 | 53 |
| Evacuation | 53 | 16. 6 | 44 | 1, 104 | 21. 9 | 40 |
| Transfer to another hospital | 22 | 6. 9 | 28 | 488 | 9. 7 | 23 |
| Total | 320 | 100. 0 | 41 | 5, 028 | 100. 0 | 36 |

*Includes only those cases in which the hand injury was the determining factor in hospitalization and disposition. All injuries include both combat- and noncombat-incurred injuries.

*Evacuation to Zone of Interior.* Indications for evacuation to the Zone of Interior included severe bone and soft tissue injuries; the loss of several digits, especially the thumb; injuries of the nerves and tendons with overlying scars which required restitution of skin before repair could be undertaken; and injuries which required reconstructive surgery. All wounds of the soft parts were completely healed before evacuation, and splints and physical therapy employed to the fullest extent indicated. The patients were carefully instructed how to carry out motions which would improve the function of

TABLE 9. PROPORTIONATE DISPOSITION OF SIMPLE AND COMPOUND FRACTURES IN CASUALTIES WITH HAND INJURIES AT THE 45TH GENERAL HOSPITAL

| Type and site of injury | Cases | Full duty | Limited duty | Evacuation |
|---|---|---|---|---|
| | | *Percent* | *Percent* | *Percent* |
| Carpal: | | | | |
| Simple | 16 | 44 | 12 | 44 |
| Compound | 35 | 6 | 11 | 83 |
| Metacarpal: | | | | |
| Simple | 15 | 46 | 40 | 14 |
| Compound | 179 | 28 | 22 | 50 |
| Phalangeal: | | | | |
| Simple | 16 | 68 | 18 | 14 |
| Compound | 118 | 40 | 32 | 28 |

TABLE 10. DISPOSITION ACCORDING TO TYPE OF INJURY OF 525 CASUALTIES WITH HAND INJURIES AT THE 12TH GENERAL HOSPITAL*

| Type of injury | Total cases | Duty | | | Evacuation | Transfer to another hospital |
|---|---|---|---|---|---|---|
| | | Full | Temporary | Limited | | |
| Penetrating wound | 60 | 29 | 13 | 8 | 5 | 5 |
| Penetrating wound with fracture | 40 | 4 | 7 | 8 | 16 | 5 |
| Penetrating wound with nerve and tendon injury | 23 | 0 | 0 | 6 | 17 | 0 |
| Penetrating wound with fracture and nerve and tendon injury | 11 | 1 | 0 | 4 | 6 | 0 |
| Perforating wound | 24 | 14 | 2 | 4 | 2 | 2 |
| Perforating wound with fracture | 73 | 8 | 2 | 19 | 35 | 9 |
| Perforating wound with nerve and tendon injury | 26 | 0 | 0 | 9 | 16 | 1 |
| Perforating wound with fracture and nerve and tendon injury | 26 | 0 | 0 | 4 | 22 | 0 |
| Lacerating wound | 36 | 22 | 6 | 4 | 1 | 3 |
| Lacerating wound with nerve and tendon injury | 25 | 5 | 1 | 10 | 7 | 2 |
| Contused wound | 6 | 6 | 0 | 0 | 0 | 0 |
| Amputation, hand or major part | 4 | 0 | 0 | 0 | 3 | 1 |
| Amputation, single digits | 35 | 4 | 6 | 17 | 5 | 3 |
| Amputation, multiple digits | 11 | 0 | 0 | 1 | 8 | 2 |
| Burns, superficial | 33 | 23 | 4 | 0 | 4 | 2 |
| Burns, deep | 17 | 1 | 2 | 1 | 11 | 2 |
| Fracture, simple | 23 | 6 | 3 | 8 | 5 | 1 |
| Infections | 45 | 33 | 5 | 1 | 3 | 3 |
| Tumors and miscellaneous conditions | 7 | 1 | 2 | 1 | 2 | 1 |
| Total | 525 | 157 | 53 | 105 | 168 | 42 |

*In all of these cases, which were observed over a 9-month period, the hand was the determining factor in disposition.

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the hand. What this amounted to was that preparation for later treatment in the Zone of Interior was actually begun overseas. Elastic traction splints were sometimes applied before the patient's evacuation to loosen the joints and make them supple. For these and similar reasons the time consumed in traveling was not a complete loss to the patient, since there was not an absolute lapse in therapy.

*Temporary Duty.* The temporary duty category was an excellent assignment for patients with injured nerves and tendons when firm healing had occurred after operation and definite signs of improvement were evident. No patient was assigned to temporary duty until the repaired nerve showed signs of beginning regeneration and the repaired tendon permitted free motion.

*Limited Duty.* Temporary or permanent limited duty was an excellent assignment for men with moderately severe injuries of the hand. The character of duty which these patients were regarded as fit to perform was always specified and it was made clear that they should not be assigned to types of labor which required any particular manual dexterity. Actual use benefited the injured hand and was psychologically better for the patient than unproductive exercises. Patients who were thus assigned were given careful instruction in the use of their hands, and the value to themselves of what they were doing was impressed upon them.

Patients in the following categories were never returned to limited duty:

1. Those who could be benefited by additional surgery.

2. Those with swollen, stiff hands, for which continued treatment was needed in a general hospital overseas or, if results were not secured there, in the Zone of Interior.

3. Patients who were reluctant to use their hands, and who did not improve when they were sent to limited duty but instead developed fixations which were difficult to overcome. These men were often shunted from job to job in a search for suitable assignments, and the constant transfers served to confirm their own opinion that their injuries were really severe and that they need not try to improve function. When once the idea was implanted in their minds that their injuries warranted their return to the Zone of Interior it was very difficult to persuade them to use their injured extremities at all.

*Full Combat Duty.* No patient was returned to full combat duty after a hand injury unless he had full, complete and free use of the hand. A man in combat should not be handicapped by a clumsy or awkward hand, for his impaired dexterity might slow his actions by a few seconds at a time when his own life or the lives of his comrades might depend on rapid motion.

The following were the chief contraindications to disposition to full combat duty:

1. Extensive loss of soft tissue.

2. Palmar scars which were tender or which would otherwise prevent free motion.

3. Scars anywhere on the hand in which neuromas were incorporated. This type of lesion causes sudden, exquisite pain on pressure or motion.

4. Extensive loss of bone.

5. Complete or partial amputation of a digit. Only very occasionally was a casualty with complete or partial amputation of any digit returned to combat duty. Those with partial amputations of the index finger or the thumb were never considered suitable candidates because of loss of grasping ability.

6. A stiff joint or joints, whether the stiffness was the result of tendon damage or of joint damage per se.

7. Extensive burns or frostbite whether or not skin grafting had been required, and injuries which had been repaired by some skin grafting procedure. Burned, frostbitten, and grafted areas were always sensitive, and while they might have withstood the ordinary trauma of life, combat conditions would not have been tolerated. Areas of thermal injury had to be protected from continued direct sunlight for long periods after healing had occurred.

8. Injuries which were followed by an attempt on the part of the patient to favor the hand and protect it from normal use.

CHAPTER IV

# Hand Injuries in the European Theater of Operations

*Mather Cleveland, M. D.**

The story of hand surgery in the European Theater of Operations began with the arrival of the first troops in England in 1942. Experience in the United Kingdom prior to D-day concerned injuries sustained by troops in training, hand infections one would encounter in civilian practice, and injuries sustained by Air Force personnel, in which infection played no part or only a minor one. With the latter exception, combat-incurred hand injuries were not seen until after D-day.

## INCIDENCE

Figures on the exact overall incidence of hand injuries in the European Theater of Operations are not now available, and possibly will never be accurately ascertained. This is for the dual reason that major injuries had precedence in record keeping and that hand injuries were not generally recorded separately. According to preliminary tabulations on percentage of hand wounds to total wounds, 7 percent of battle casualty admissions for 1942 and 1943 were for hand wounds and injuries. These data represent only those cases for which the specified injury or wound was reported as the primary cause of admission to medical treatment and exclude cases treated as outpatients.[1] Individual reports from several hospitals will, however, give some indications on type and frequency of hand injuries.

Among the 1,738 patients [2] with orthopedic conditions who passed through the 298th General Hospital, Frenchay Park, Bristol, England, during the year prior to the invasion, 31 had simple fractures of the scaphoid and 3 had fractures of bones other than scaphoid, 16 had simple or compound fractures of the metacarpal bones, 36 had simple or compound fractures of the phalanges, 15 had sprains of the wrist, 2 had deformities of the fingers, and 2 had acute hand infections.

Between September 1944 and April 1945, when the 814th Hospital Center was installed in the Hôpital de la Pitié in Paris, there were 8,211 orthopedic

*Consultant in Orthopedic Surgery to Veterans Administration, Area I, and to The Surgeon General, United States Army. Formerly Colonel, MC, AUS.

[1] Memo, Chief, Med Stat Div, SGO, for Editor-in-Chief, HU, AMS, 18 Nov 53. HD: 314.7–2 (Hand Surgery, ETO).

[2] According to the Senior Consultant in Orthopedic Surgery, Lt. Col. (later Col.) Mather Cleveland, 500 to 600 more patients were seen than these numbers would indicate, but for one reason or another the cases did not reach the record department of the orthopedic section.

admissions, 5,172 of which were battle casualties.[3] Of the total admissions, 357 were for fractures of the metacarpals and 203 for fractures of the bones of the fingers. Roughly, therefore, 1 out of every 15 orthopedic admissions was for a fracture of the bones of the hand.

An analysis of 64,389 United States Army battle casualities treated in 12 evacuation and 5 field hospitals of the Third United States Army from 1 August 1944 when this Army became operational to 1 February 1945 showed that 16,327, approximately 25 percent of the total number, had injuries of the upper extremities, of whom 0.3 percent died. Of 1,365 amputations performed on 1,290 patients over the same period, 35 were of the hand or of parts of the hand.

In 747 compound fractures seen in 610 patients admitted to the orthopedic, section of the 61st General Hospital, Broadwell Grove, near Burford, Oxon, England, between 15 July and 1 November 1944, 54 were compound fractures of the phalanges, 73 of the metacarpals, and 37 of the carpals.[4]

At the 19th General Hospital, Nancy, France, of 379 orthopedic patients operated on for delayed primary closures of wounds between 18 February and 31 May 1945, 31 had injuries of the hand.[5] [A total of 881 closures were carried out in these 379 patients.]

In April 1945, when the 50th General Hospital at Commercy, France, was designated as the hand center for the 819th Hospital Center,[6] there were 96 hand patients in the hospital. Many had been in 2 to 4 hospitals for varying lengths of time before arriving at the 50th General Hospital. There were 166 additional hand patients admitted to the hand center before V–E Day. (The average time from injury to arriving at the hospital was 6.7 days, a time lag significantly longer than it should have been.) In the 166 patients there were 48 soft tissue injuries, 3 burn cases, 3 dislocations, 6 simple fractures of the phalanges, 7 simple fractures of the metacarpals, 55 compound comminuted fractures of the phalanges, 16 compound comminuted fractures of the metacarpals, 13 compound comminuted fractures of the metacarpals, and phalanges combined, and 15 surgical and traumatic amputations.

The average time between injury and return to duty was 38.8 days. Eighty-two percent of the patients were returned to duty; 18 percent were sent to the United Kingdom or the Zone of Interior for further observation and treatment because of the 60-day holding policy. The number of patients returned to full duty for this group was higher than the average for the hospital during this period (1 January to 1 June 1945), 64 percent, and was higher than that reported by other observers who worked in hospitals much farther to the rear.[7]

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[3] Figures supplied by Maj. W. H. Blodgett, Chief of Orthopedic Surgery in the 217th General Hospital and Consultant in Orthopedics for the 814th Hospital Center. Annual Rpts, 1st, 40th, and 217th Gen Hosps, 1944. HD.

[4] Annual Rpt, 61st Gen Hosp, 1944. HD.

[5] Annual Rpt, 19th Gen Hosp, Jan–Jun 1945. HD.

[6] ETO Surg, Cir Ltr 32, 6 Apr 45, sub: Hospitals for specialized treatment on the Continent. HD.

[7] Annual Rpt, 50th Gen Hosp, Jan–Jun 1945. HD.

## OFFICIAL POLICIES ON CARE OF INJURED HANDS

The *Manual of Therapy, European Theater of Operations*,[8] issued 5 May 1944, contained no specific instructions for the management of wounds of the hand. Presumably the intention was that the principles set forth therein for soft tissue wounds and fractures were to be applied in the treatment of these injuries.

It promptly became evident that while the *Manual of Therapy* was adequate so far as the broad surgical principles were concerned, it needed amplification to provide guidance to the younger and often inexperienced surgeons in dealing with specific situations. Compounding the need for more detailed instructions were the large numbers of surgeons who were being assigned constantly to the theater but were only partially trained in treating combat injuries of the bones and joints.[9]

As a consequence, Circular Letters 101[10] of 30 July 1944 and 131 of 8 November 1944 were issued. The first dealt in general terms with the care of battle wounds. The second, however, provided specific instructions on hand injury management (see Appendix A, this chapter).

A short time later Circular Letter 23[11] was issued from the Office of the Chief Surgeon which contained a section on orthopedic surgery under the heading of *Notes for disposition boards:*

> Under the present evacuation policy to the Zone of the Interior, very few simple or compound fractures can be rehabilitated to full duty in this theater. [The Continental holding period at this time was 60 days.—Ed.] Among the exceptions may be certain fractures incurred by key personnel occupying sedentary positions. A fracture of the . . . metacarpal bones . . . or phalanges are cited as examples of fractures that may be returned to full duty within the present evacuation policy. There may be a few other instances of minor fractures which will require careful evaluation in order to determine whether there is any possibility of salvaging the officer or soldier involved for further duty in this theater within the time allowed.

The final directive on this subject, Circular Letter 39, was issued 5 May 1945 and contained a section dealing exclusively with the care of hand injuries (see Appendix B, this chapter).

These circular letters cited contained all the instructions issued officially on the subject of hand injuries during the fighting on the Continent 6 June 1944 to 8 May 1945.

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[8] Manual of Therapy, European Theater of Operations, 5 May 44. HD.

[9] In June 1944 there were some 63 diplomates of the American Board of Orthopedic Surgery in the European Theater of Operations. Six of these were immobilized as consultants or commanding officers and in other administrative capacities, or had been returned to the Zone of Interior, so that only 57 were available for the actual care of the wounded. To supplement these "elder statesmen," there were some 95 officers who had had partial civilian training in orthopedic surgery and 85 general surgeons who had had training in traumatic surgery. The remaining officers who filled the additional 175 positions, with a specialist rating in orthopedic surgery, had received their entire training in the Army (Cleveland, M.: Orthopedic surgery in the European Theater of Operations. Ann. Surg. 124: 188–200, 1946).

[10] ETO Surg, Cir Ltr 101, 30 Jul 44, sub: Care of battle casualties. HD.

[11] ETO Surg, Cir Ltr 23, 17 Mar 45, sub: Care of battle casualties. HD.

## EVOLUTION OF THERAPY FOR HAND INJURIES

The approximation of an ideal technique for treatment of hand injuries was gradual and was achieved by a process of evolution as the war progressed. There was increasing interest in and emphasis on the management of wounds of the hand by all surgeons in the theater. This interest was evidenced in reports from many who were intensely concerned with the poor functional results being obtained in hand surgery.

In one instance, the Chief of Orthopedic Surgery, 61st General Hospital, stated that it was the consensus in that hospital that if it were possible to perform early definitive surgery on the more serious hand injuries in the forward hospitals significant reduction could be expected in the convalescent period and eventual disability so common in hand patients. That this would entail a priority for such injuries similar to that for maxillofacial injuries was apparent. Certainly the functional results in the hand are as important to the soldier

TABLE 11. HOSPITALS DESIGNATED FOR SPECIALIZED TREATMENT OF HAND INJURIES IN THE EUROPEAN THEATER OF OPERATIONS

United Kingdom [1]

| General hospital | Location | Hospital center |
|---|---|---|
| 22d | Anson & Craddock Barracks, Pimperne, Dorset | 802d. |
| 53d | Merebrook, near Hanley Swan, Worcester | 12th. |
| 61st | Broadwell Grove, near Burford, Oxon | 15th. |
| 65th | Redgrave Park, near Botesdale, E. Suffolk | 805th. |
| 117th | Frenchay Park, near Bristol, Gloucester | 803d. |
| 129th | Penley Hall, near Penley, Flintshire | 804th. |
| 156th | Foxley No. 1, near Mansell Lacy, Herefordshire | 12th. |
| 158th | Odstock, near Salisbury, Wiltshire | 802d. |
| 185th | Sandhill park, Bishops Lydeard, Somerset | 801st. |
| 192d | Cirencester No. 2, near Cirencester, Gloucester | 15th. |

On the Continent [2]

| | | |
|---|---|---|
| 1st | Paris, France | 814th–815th.[3] |
| 2d | Nancy, France | 820th. |
| 21st | Mirecourt, France | 820th. |
| 40th | Paris, France | 814th. |
| 50th | Commercy, France | 819th. |
| 217th | Paris, France | 814th. |
| 298th | Liége, Belgium | 818th. |

[1] Annual Rpt, Off of Surg UK base, 1944, App 11. HD.

[2] ETO Surg, Cir Ltr 32, 6 Apr 45, sub: Hospitals for specialized treatment on the Continent. HD.

[3] Until 14 February 1945, the 815th Hospital Center was attached to the 814th Hospital Center on an inactive status (Final Rpt, 815th Hosp Ctr, 1945–2. HD).

and the government as are the cosmetic results of a face wound. Such surgery would require a certain degree of specialized knowledge as well as uniform application of fundamental principles, and ideally such surgery should be done by or under the supervision of specially instructed personnel or teams. To insure continuous observation the suggestion was made that it would seem advisable to transport hand injury cases to a centrally located hospital in the communications zone where aftercare and rehabilitation could be started, and where the adequacy of treatment in the forward hospitals could be evaluated. Such a program, it was believed, would greatly reduce the number and extent of hand disabilities.[12]

## DESIGNATION OF HAND CENTERS

During midwinter 1944, centers for other specialties were established in the United Kingdom, but not until the following spring were centers for the special care of hand injuries designated.[13] The 10 hand centers in the United Kingdom preceded by several months the establishment of 7 on the Continent (Table 11).[14] It was not until air and other evacuation to the United Kingdom was delayed that the Chief Consultant in Surgery,[15] with the cooperation of the Senior Consultants in Plastic and Orthopedic Surgery, began designating centers for specialized hand care on the Continent.

## SURVEY OF HAND CENTERS IN THE UNITED KINGDOM

On 23 March 1945, Maj. Bliss B. Clarke[16] of the 1st General Hospital, Paris, France, reported to the Senior Consultant in Orthopedic Surgery, European Theater of Operations, on his tour of the hand centers in the United Kingdom in February of that year. Hand injuries were not being properly treated and the end results were poor, the report stated. Treatment was being delayed and the importance of the hand and its function were not properly appreciated by most surgeons. This comprehensive report included the following suggestions:

*Treatment of the Wound.* 1. The initial treatment of hand injuries should be preceded by a careful and complete scrubbing of the hand for 10 minutes with green soap, then washed with sterile saline solution and rinsed with alcohol and ether. The fingernails should be cleaned and inground dirt removed.

2. Debridement should be thorough but also conservative. The vascularity of the skin and underlying tissues of the hand, and the scantiness of the musculature, make it essential that as much skin and other tissue as possible

[12] Duncan, W. R.: Report on early definitive hand surgery. M. Bull., ETO, May–Jun 1945. HD.
[13] Semiannual Rpt, Chief Consultant in Surgery, ETO, 1945–1. HD.
[14] See footnote 6, p. 156.
[15] See footnote 13 above.
[16] Rpt, Maj Bliss B. Clarke to Col Mather Cleveland, Senior Consultant in Orthopedic Surgery, ETO, 23 Mar 45, sub: An outline of treatment for the wounded hand. HD: 730 ETO (Hand injuries).

should be saved and that debridement should be minimal unless tissue is clearly necrotic. If enough skin can be saved to effect closure, healing and restoration of function will be expedited.

3. Closure should be accomplished whenever possible, and especially when tendon and bone are exposed, in order to prevent infection and to avoid the tissue reaction which is inevitable in an open wound and which leads to edema, swelling, pain, stiffness, and eventually fibrosis. Fibrosis can occur within 3 weeks of injury. There are no underlying muscle masses and no fascial planes in the hand, and sheath and fascial-space infections following hand injuries are therefore uncommon and can be dealt with if they occur.

Exposed areas should be covered with a split thickness graft, which acts as the finest dressing obtainable. Later, if tendon and bone grafting are necessary or loss of soft tissue makes the use of a pedicle flap advisable, the split thickness graft can be removed readily. In the interim, however, the reaction in the hand will have been minimized, motion will have been started, and fibrosis will have been prevented.

4. All foreign bodies that are readily accessible should be removed. Do not remove others which require probing and dissection, as this merely adds additional trauma to an already injured hand. Foreign bodies can be adequately dealt with at a later date if this procedure is deemed necessary.

5. Neither tendons nor nerves should be repaired at the initial operation. Repair should be done early but the operation is long and tedious and can be better accomplished in a rear echelon hospital.

*Treatment of Fractures.* 1. In the forward areas, immobilization is the most important consideration and the following general principles are suggested as guides:

*a. Immobilize if over 50 percent of the function of the hand is lost.* Immobilization should be provided by a plaster volar splint not quite reaching the proximal joints, with a narrow split projection of the splint holding the thumb in abduction. A simple way to remember the position in which the hand should be immobilized is to imagine grasping a large indoor baseball. The fingers are partially flexed in a rounded arc and the thumb in moderate opposition and partially flexed. This is an ideal position for a hand at rest. Changes can be instituted for definite treatment and with the hand in this position fibrosis can do the least damage if prolonged immobilization accidentally occurs.

*b.* If over 50 percent of the function of the hand, *including the function of the damaged portion*, is retained, motion should be begun without delay. The figure of 50 percent is chosen for a definite reason. The objective of early motion is twofold: (1) to prevent stiffness in the joints and moving parts by preventing contractures and thickening of the ligaments and capsular structures about these parts, and (2) to prevent edema. To combat both of these (stiffness and edema) it is felt that at least 50 percent of range of motion of a damaged part must be present. Therefore, the term "over 50 percent"

is used. If motion of this degree is present, *and can be maintained*, both edema and stiffness will be adequately controlled.

*c.* If the hand is not to be immobilized it should be bandaged using the smallest dressing possible consistent with adequate coverage of the wounds. There should be little or no resistance to movement of the hand or fingers.

*d.* When a joint of a finger is wrecked and a tendon is missing, optimism over possible salvage of the finger is misplaced. In many cases the conservative plan is to waste no time in amputating the badly damaged finger.

2. The hand should be elevated at all times—elbow above shoulder. This is best accomplished with a simple traction apparatus, consisting of a rope, pulley, and weight. Early motion and pressure dressings are of assistance in preventing post-traumatic and postoperative edema, but the most effective method of preventing it, or of combating it if it has occurred, is by continuous elevation of the part.

3. Educate the patient. It should be pointed out to the patient that the hand is more important than the eye, and is next in importance to the brain iself; that it is a delicately integrated and highly complex part of the body, which has been largely responsible for man's evolutionary development. The patient who understands these facts will need little persuasion to keep his hand elevated and to keep the whole hand, the fingers, the wrist, the elbow, and the shoulder in constant motion.

In the same month (March 1945), Lt. Col. Eugene M. Bricker, Senior Consultant in Plastic Surgery, European Theater of Operations, outlined the principles of plastic surgery suitable for the management of combat injuries in a memorandum to the Senior Consultant in Orthopedic Surgery:[17]

1. Conservative, careful and thorough debridement of the primary wound is essential. Primary closure[18] is not advised in an evacuation hospital, but skin flaps can be dressed back into place.

2. Splint purposefully, maintaining the palmar arch and flexion of the metacarpophalangeal joints.

3. Bring about delayed closure as early as possible, preferably on the third or fourth day, by simple closure, split graft or pedicle graft, according to the necessities of the case.

4. Use traction only when it is urgently indicated, and then for a minimum length of time. Fish-hook traction, that is, traction through the middle of the dorsal surface of the middle phalanx, utilizing a fish-hook minus the barb, as practiced at the 22nd General Hospital, is probably the most efficient.

5. Concentrate on maintenance of such function as remains following certain severe types of injury. Restoration of the injured part should not be attempted, and healing should be accomplished as rapidly as possible. Amputation of an irreparably damaged finger is justified.

6. Institute active motion as early as possible, and supplement by occupational therapy when healing has occurred.

[17] Memo, Lt Col E. M. Bricker for Senior Consultant in Orthopedic Surgery, ETO, Mar 1945, sub: Treatment of hand injuries. Personal files of author.

[18] See Appendix B, item b (1) (c). See also pp. 163, 176, and Chapter II, p. 42 on primary closure.

7. Try to prevent edema and infection in open wounds. Proper debridement, proper dressings, proper splinting, and effective elevation of the hand will prevent this development.

8. Manage an open wound aseptically as long as it remains open. Aseptic management implies the use of masks and of instruments or gloves, whether or not the wound is infected.

Adding impetus to the need for better care of hand injuries was a report received from Maj. George Hammond,[19] Chief of the Orthopedic Section, 298th General Hospital, Alleur, Liége, Belgium, and Orthopedic Consultant for the 818th Hospital Center. The report stated that debridements were being improperly performed; delayed primary skin closure and skin grafting were being unduly deferred or were being omitted altogether. Fractures were being neglected; normal fingers were being immobilized. When immobilization was done, it was often continued for too long a time. There were both delay and neglect in the comprehensive program of physical and occupational therapy and rehabilitation of hands following war wounds and fractures.

The basic reason for these improper practices, the report indicated, was the fact that the relative importance of the hand, compared to other parts of the extremities, was overlooked and in some medical installations seemed never to have been realized at all. It was common practice, consequently, to assign the management of these injuries to surgeons who had the least surgical experience.[20] And since these casualties often had no other injuries and were ambulatory, the tendency was to neglect optimum treatment in periods of pressure where emphasis was on rapid admission and evacuation. After a hasty debridement, patients were moved from hospital to hospital in the chain of evacuation and received no definitive care until it was too late to achieve good results by any method of treatment. Wounds became infected, scarring was advanced, joints were stiff and bone fragments malunited by the time many patients reached a general hospital, were removed from the line of evacuation, and given special care.

Further complicating the problem, according to the report, were directives stating that fractures were to be disregarded and hand injuries treated only as soft tissue injuries. Fractures were more neglected subsequently than they had been previously, while improper plaster immobilization of the entire hand was replaced by bandage encasement, which, in effect, soon became a cast because of drying and hardening of bloody exudate.

To improve the quality of hand care administratively, it was suggested that:

1. The principles of war surgery of the hand should be emphasized to the surgical personnel in every hospital, and instruction in special classes be given in selected hospitals.

[19] Rpt, Maj George Hammond to Senior Consultant in Orthopedic Surgery, ETO, Jul 1945, sub: History of the Orthopedic Section, 298th Gen Hosp. Personal files of author.

[20] Similar criticism was expressed by the 3d Auxiliary Surgical Group operating in Germany during this period (First Semiannual Rpt, 1945. HD).

2. Consultants should repeatedly check the treatment of hand injuries.

3. Hospitals noting errors of treatment in previous installations should be encouraged to call attention to them by notification of the erring surgical services via the most efficient official channels of communication.

4. Combat-incurred hand injuries should have priority in evacuation at least equal to, and preferably higher, than that given to fractures of the long bones. A method of evacuation should be established whereby these casualties should reach hospitals specially qualified to take care of them in the minimum possible time.

5. Directives should thoroughly cover principles of treatment.

6. A senior surgeon should perform the debridement in all hand injuries, or should himself examine the injury before designating another surgeon for the task.

The report then set forth the following clinical policies:

1. Thorough skin preparation should be carried out before operation; debridement should be thorough and careful and the greatest possible conservatism should be exercised in the excision of skin or bone fragments.

2. Severed tendons should not be sutured definitively, though whenever indicated the ends might be united by a simple mattress suture to prevent retraction and facilitate subsequent suture.

3. The wound should not be sutured. A small amount of fine-meshed gauze, as little as possible, should be inserted to hold it open. (There was no doubt, the report stated, that certain wounds of the hand can be successfully closed by immediate primary suture, but this method should not be encouraged, partly because of the risk of complications and partly because of the successful results which can be accomplished without risk, by delayed primary closure.)[21]

4. All fractures should be treated. (It is true, the report stated, that certain fractures without displacement of fragments do not require immobilization and are not harmed if motion is begun as soon as the soft tissue wound permits. However, most combat-incurred fractures of the phalanges and metacarpals are associated with significant displacement of fragments and require active treatment. If fractures of this kind are not reduced, or immobilized, malunion or nonunion occurs. For this reason stable fragments should be reduced and held in place by plaster immobilization, while unstable fragments should be held in place after reduction by continuous skin traction, or occasionally, skeletal traction.)

5. Fractures should be immobilized only long enough to secure firm union.

6. Normal fingers should never be immobilized and should be moved for 10 minutes out of every hour, beginning immediately after the initial operation.

7. As soon as immobilization is discontinued, a comprehensive program of physical and occupational therapy should be begun and the patient should be encouraged repeatedly to undertake both painless passive and active motion of the stiffened joints.

8. Delayed primary suture of the wound and any necessary skin grafting should be carried out promptly, preferably within 3 to 5 days after wound excision.

9. The hand should be elevated after injury and after operation for a sufficient length of time to be certain that edema and swelling will not occur.

## EXPERIENCES IN HAND CENTERS

The most important advance in treatment of hand wounds was accomplished when hand centers were established. At these centers, closure of hand wounds was accomplished by delayed primary suture, if possible, or by split

[21] See footnote 18, p. 161.

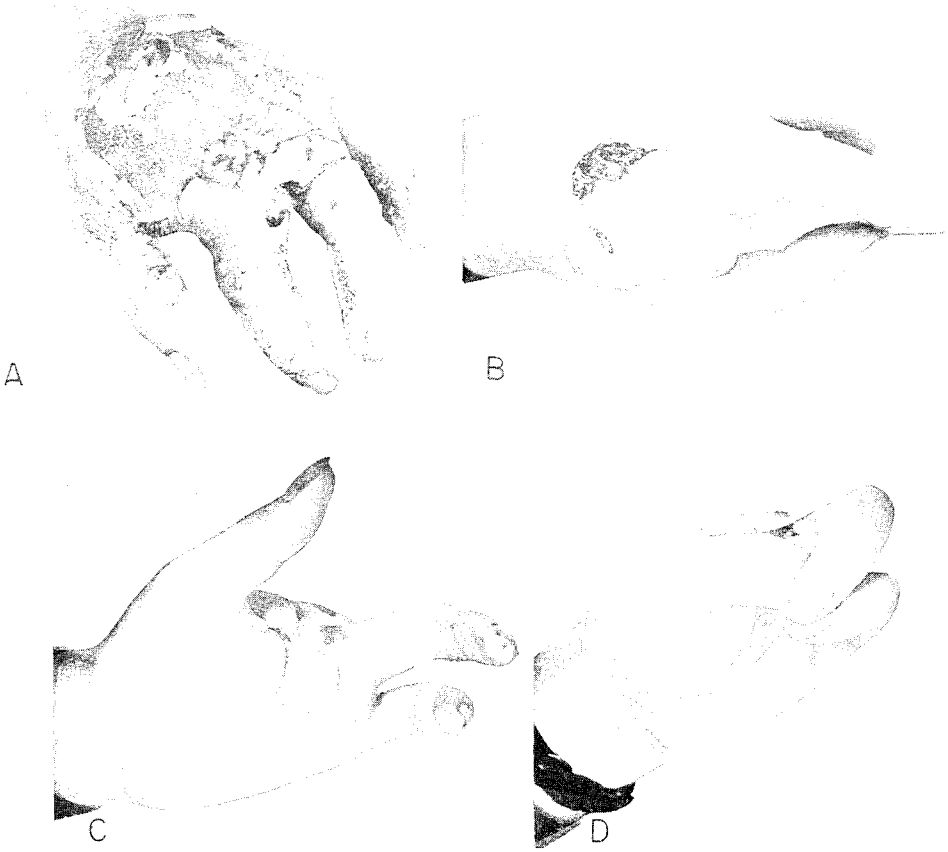



*Figure 65. A. Preoperative view of severely injured hand, with index finger blown off and middle finger badly shattered and functionless. B. Dorsal view of same hand after healing following reparative surgery. The skin of the middle finger, which was amputated because it was functionless, was used to cover the dorsal defect. C. Palmar view of same hand after healing. D. Demonstration of function in fingers and thumb after healing.*

thickness free skin grafts. Less often, when bones or tendons were exposed, pedicle skin grafts were done. The flap graft from a useless, deboned finger, was often utilized in covering defects of the palm or dorsum of the hand (Fig. 65). Skeletal traction, applied through the proximal or middle phalanges was at times employed to secure reduction and immobilization of metacarpal fractures. It was seldom applied for more than 14 to 16 days. Pulp traction was forbidden, since gangrene of the fingertips resulted in a number of early cases when this form of treatment was employed in patients during transfer from forward to rear hospitals.

Infections occurring in wounded hands were treated with the usual surgical care. Superficial infections responded well following application of hot

wet packs for 2 to 3 days. The hand was kept elevated. Sulfonamides or penicillin, or both, were usually administered parenterally. Surgical drainage was resorted to if necessary. Ischemic tissue was debrided and foreign bodies, where easily available, were removed.

Amputation of hands or fingers was a final, definitive step which was not carried out unless there was absolutely no possibility of restoring some useful function to the part or unless circulatory impairment had resulted in complete necrosis. When amputation was necessary it was always performed at the most distal point possible, since any part of the hand which could be salvaged for function was regarded as preferable to a prosthesis. The single exception to strict conservatism in the matter of finger amputation was the presence of a compound fracture of a finger with destruction of both the flexor and extensor tendons. Prompt amputation of such a digit, with early active motion of the remaining fingers and hand ensured a more serviceable member from the patient's standpoint and often permitted a prompt return-to-duty status.

## The Hand Center at the 129th General Hospital

*(804th Hospital Center)*

Reports from hand centers furnished the most comprehensive information concerning the special problems of hand surgery in the European Theater of Operations and the methods by which they were met. One extensive report was made by Lt. Col. Philip S. Foisie, Chief of Surgical Service at the 129th General Hospital, which had been designated as a hand center 30 March 1945,[22] to receive all hand injuries admitted to the 804th Hospital Center, Whitchurch, Shropshire, England.[23]

Two wards were set aside originally for hand injury cases, and adjacent wards and tents were used to house additional admissions. All activities were concentrated on the two basic wards, and as discharges occurred, patients were brought from other wards into them.

The report stated that it was hoped that with the patients segregated and treated as a distinct group, with all activities concentrated in a separate unit, there could be built in the men a consciousness of the importance of hand function and a psychology of cooperation with the surgeons.

The concentration of activities saved the time of surgeons, ward officers, nurses, and other attendants, as well as the time of the patients. When the physical therapy department was at the other end of the hospital from the ward, a patient sent for treatment often paused along the way at the post exchange, post office, Red Cross office, or elsewhere, all of which had their proper place in hospital life but which could be distracting at the wrong time. Con-

[22] Annual Rpt, 129th Gen Hosp, 1945–1. HD.

[23] This report was received about 6 weeks after hostilities ceased.

centration of activities in the same wards permitted better supervision and control of the patient, and made him as well as the staff, hand conscious. Soldiers who were not being actively treated at the moment saw their comrades being treated and were more anxious to cooperate when their turns came. By keeping activity constantly before them, they were motivated to think in terms of use, exercise, and function as far as they themselves were concerned.

At this center a special graphic chart was provided for patients with hand injuries, consisting of a mimeographed sheet, with skeletal outlines for each hand. The reverse of the sheet was used for history and progress notes. The ward officer who took the history and made the examination indicated on this chart the location and extent of the injury. At the same time the surgical problem was evaluated and the outline of treatment suggested. Suitable consultations were requested and roentgenograms were ordered. The patient could then be presented, with all the data available, at the next surgical rounds, when a final decision concerning his hand-care management would be made.

### Clinical Measures

Many patients were admitted to this hand center with large open wounds, their hands still in the plaster which had been applied following debridement. In some instances the injury had occurred as long as 3 to 4 weeks previously. The first problem in such cases was to close the wound. If sufficient skin were available, simple delayed primary closure was sometimes sufficient; more often grafts were necessary. When denudation was superficial, even though the area was large, free skin grafts were adequate. For deeper wounds in which nerves, bones, or tendons were exposed, pedicle grafting was usually done. Pedicle grafting was also done when subsequent surgical procedures were likely to be necessary. Flaps were raised and attached to the defect at once and the extremity was fixed in plaster for 3 weeks. The donor site was covered with free skin. An experienced plastic surgeon,[24] [25] consulted on this work performed many of the operations.

If the wound seemed clean, closure or application of the graft, whether free or pedicle, was done at the time of the first dressing. Ideally, closure would have been accomplished by the end of the first week after debridement, preferably without interim dressings. Dressings, even if carefully done, introduced an element of infection. In patients who were admitted to the hand center later than a week after debridement as little additional time as possible was lost in closing the wound.

In some cases large defects of the hand could be covered by the whole thickness of the skin of an irreparably damaged finger in which the blood supply still existed although the bones were shattered and the tendons gone. It

[24] Lt. Col. Melvin F. White, MC, Consultant, Maxillofacial and Plastic Surgery, 129th General Hospital, 804th Hospital Center (Annual Rpt, 1945–1. HD).

[25] See footnote 13, p. 159.

was the practice to remove the remaining bone and tendon and employ the flesh of the finger as a sort of pedicle graft (Fig. 65). When the finger was turned over at the palmar junction and the tissue was split, it covered a surprisingly large area and afforded an excellent pressure surface.

The surgeons at the 129th General Hospital were in full accord with Bunnell's emphasis on the dangers of flat immobilization of hand injuries [26] and on the importance of maintaining the position of function during immobilization if maximum function is later to be expected. Overimmobilization and immobilization in improper positions persisted to the end of the war. Numerous patients were received whose hands had been in plaster for many weeks. Some of them had multiple fractures with considerable loss of bone, a type of injury in which immobilization is useless. Remarkably good functional results were secured when the plaster was removed, the wounds were closed, and active motion was begun. One patient, who had had practically every bone in his hand and wrist shattered by a mine explosion, left the center able to shave with the injured hand, write, play a guitar, and do very presentable clay modeling; his treatment in this hospital had consisted only of wet dressings and active exercise.

Many times even the most cooperative patient could not move his hand fully until some manipulative or operative procedure was performed. At the first examination stiffness was frequently relieved by manipulation according to the method described by Bunnell.[27] In other cases the freeing of adhesions and excisions of scars causing contractures were necessary. If tendons were caught in old scars, function was improved when active exercise was preceded by lysis. After scars causing contractures had been excised, a more satisfactory closure of the wound could be accomplished, by grafting if necessary.

Tendon repairs were not usually indicated in an overseas hand center. In an occasional case, repair immediately after injury was justified, but if this was not practical, it was necessary to wait until the inflammatory reaction had fully subsided. Repairs carried out in recently healed wounds were never satisfactory.[28]

Function was sometimes improved by the removal of foreign bodies, even if they were very small. Their presence usually worried the patient, and pressure symptoms acted as a deterrent to full motion. It was often difficult to know whether the foreign objects were really causing symptoms or were merely providing a psychic handicap, but in either instance improvement in function was likely to follow their removal.

### Psychologic and Physical Factors in the Restoration of Function

The new patient was given a copy of a booklet prepared in the hospital, called *The Hand Book* (Fig. 66) in which by the presentation of pictures,

[26] [27] See Chapter II.

[28] See 61st General Hospital experiences on tendon repair, p. 172, this chapter.

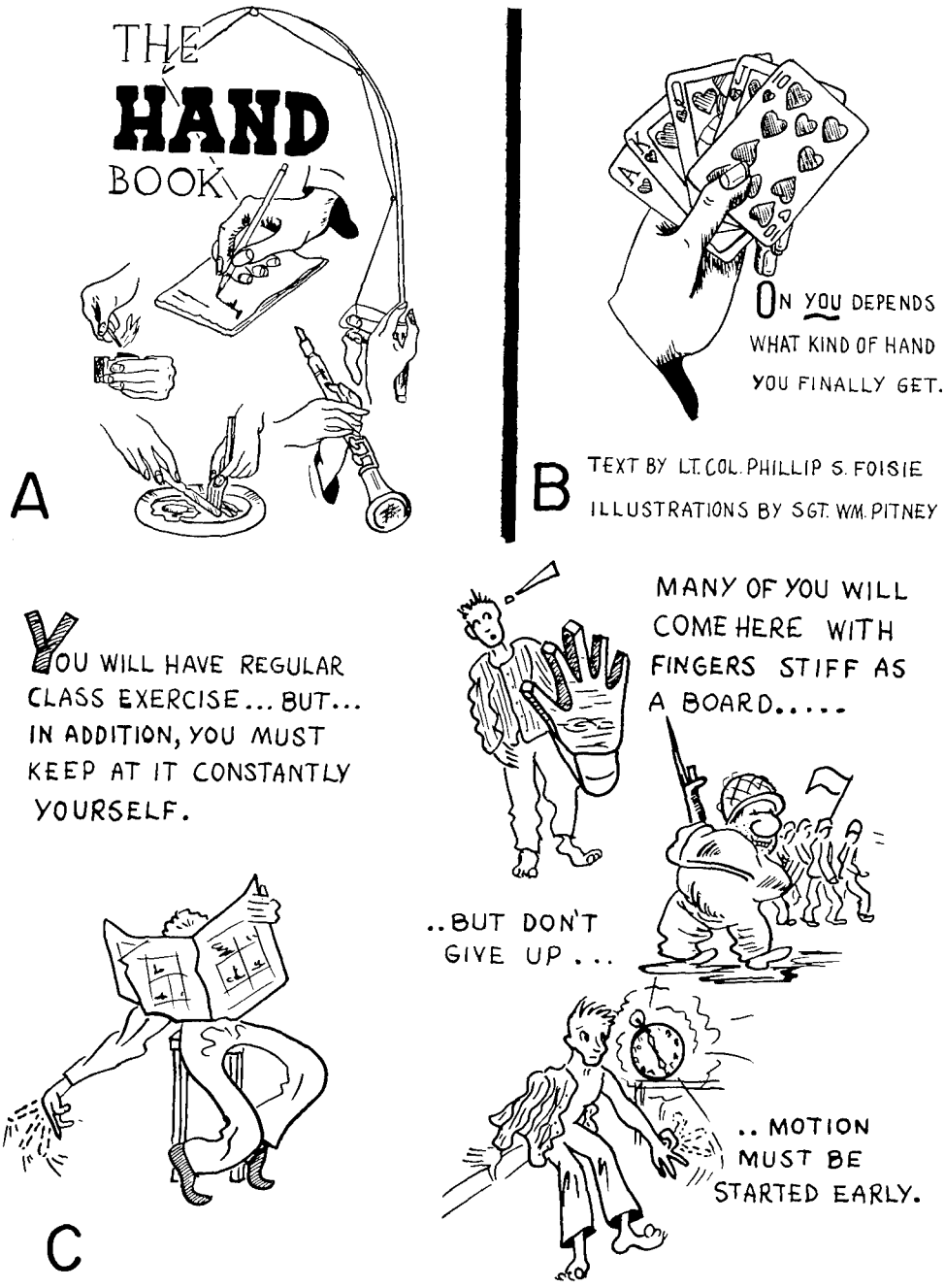



*Figure 66. Cover (A) and sample pages (B and C) from The Hand Book, a pamphlet prepared at the 129th General Hospital to teach patients on the hand surgery wards the importance of hand function.*

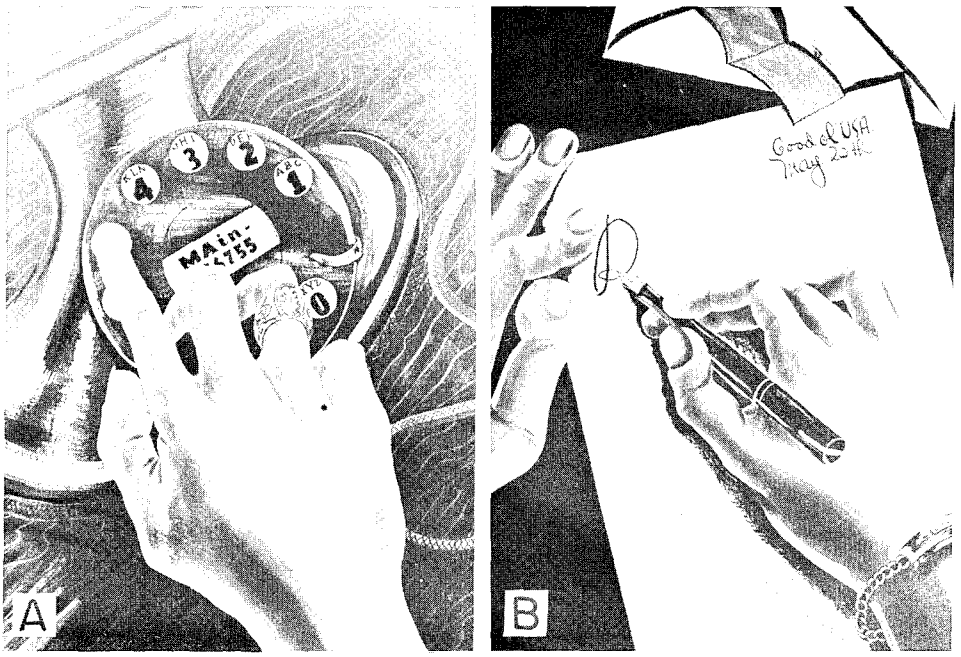



*Figure 67. Sample posters used on hand wards of the 129th General Hospital to emphasize the patient's own share in the restoration of hand function.*

chiefly in a light vein, the attempt was made to make him understand the problem of hand function. It proved a useful supplement to personal instruction and encouragement (see Appendix C, this chapter). In each of the hand wards there was also prominently displayed a series of 12 colored posters (Fig. 67) which had been prepared by a patient who was an artist. The posters emphasized only the hands, the background being merely sufficient to tie in the action. By these and other methods surgeons, nurses, technicians, and patients were kept constantly aware of the importance of the function of the hand.

The first step in the restoration of function was the institution of movement, and here the patient's cooperation was more easily secured by encouragement and example than by threats and restraint. Cooperation proved contagious. On ward rounds patients who had made good progress were always warmly praised for their efforts; those who were not cooperating received no praise, though the soldier was never blamed publicly. If a patient did not wish to get better there was not much professionally that could be done about it. If he elected to keep his hand stiff, no physician could cure him. While some patients had the idea that they would like to retain their disability long enough to delay frontline service, or avoid it altogether, very few elected to cripple themselves for life when it was once made clear to them that if they did not regain lost function at once the chances were against its ever being regained.

All sorts of devices and activities were employed to restore function to the hands and fingers (Fig. 68). Special types of apparatus had their place, but were worthless unless constant supervision was maintained. The most commonly used device was an extension exerciser made from a bicycle spoke fixed to a plaster or plexiglass cup which maintained slight, steady extension. The patient wore it constantly and it provided active exercise against passive resistance. It proved valuable in cases in which ability to extend the fingers had been impaired, as well as in cases of radial paralysis. If the traction arrangement was placed on the volar surface of the hand, flexion was similarly aided. When it was used to combat stiffness of the fingers, care had to be taken to keep the wrist immobilized; otherwise the patient was likely to move the wrist and keep the fingers stiff. Whenever a device of this sort was used it was most satisfactory if it could be removed readily, so that physical therapy, massage, skin care, and other measures need not be interrupted.

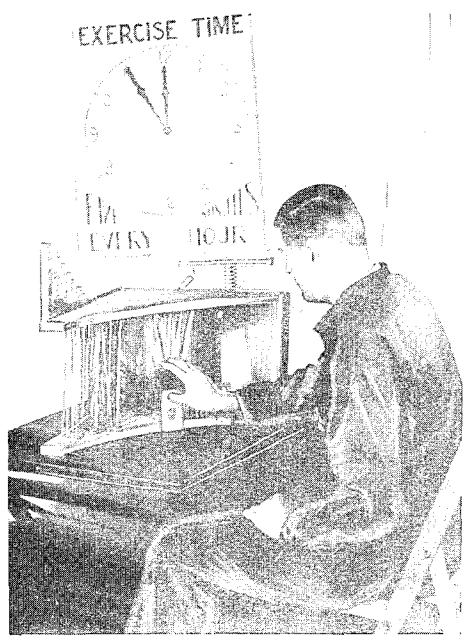



*Figure 68. Typical devices to exercise the hands after injury. Rehabilitation gymnasia were well provided with such gadgets, but unless the patients were required to use them in supervised classes they were little more than window dressing.*

Massage and physical therapy remained the bulwark of treatment for stiff joints. Both measures took time and required trained and skilled personnel, but there was no adequate substitute for them. The ordinary physical therapy department could not handle the work of a hand center. The setup and per-

sonnel had to be sufficient to permit at least a half hour of personal attention for each patient daily. Exercise, to be effective, had to be on an all-day schedule. This idea was constantly emphasized at the 129th General Hospital. Whirlpool baths were installed and the hand wards were provided with heat lamps.[29] A therapist gave full time to massage, with the assistance of extra technicians and the cooperation of the entire department. Included in the massage period were active and passive exercises, with careful instruction in exercises which the patient might carry out himself. This instruction was most important. Patients were likely to take a passive attitude and to leave it to the physical therapist to do the work unless they were convinced that they themselves had to take an active part in all procedures and that their formal treatment was only the beginning. If they did not have this conviction, physical therapy did more harm than good, for it lulled them into exclusive dependence on it.

Every endeavor was made to supply activities which would keep the patients interested while they exercised their hands. Attached to each of the hand wards was a room equipped with tables, stools, full sets of tools, and salvaged material, such as scrap plexiglass, plywood, aluminum, propeller blades and other parts of wrecked planes, scrap metal, wire and lumber, from which bracelets, rings, picture frames, and other articles could be made (Fig. 69). A full-time Red Cross worker taught weaving, modeling, and other

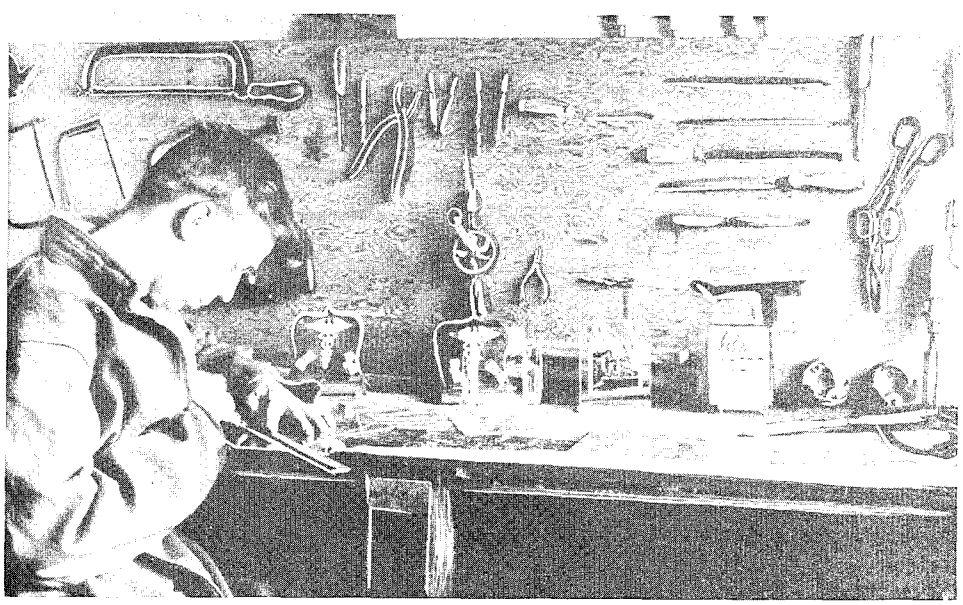


*Figure 69. Typical workshop set up in a private room on a hand ward. A few of the products made by patients with injured hands are displayed.*

[29] For another expression on whirlpool bath therapy, see Chapter III, p. 119.—Ed.

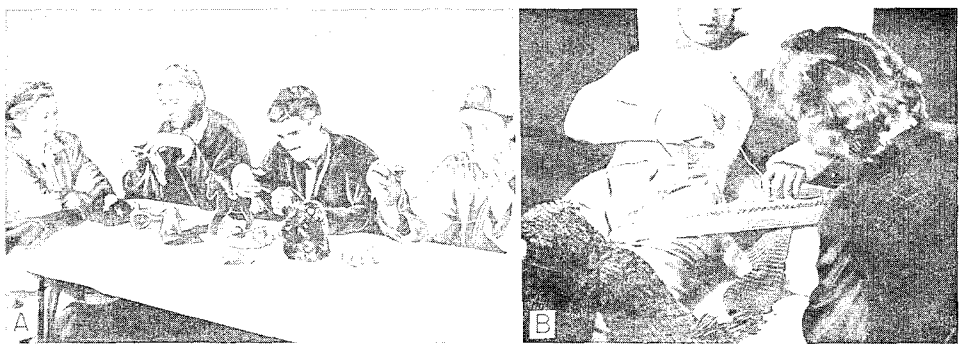


*Figure 70. A. Red Cross worker giving group instruction in various crafts to patients with injured hands. B. Scarfmaking by patient with both hands injured.*

forms of handicraft (Fig. 70). It was frequently difficult to interest men in these activities if they worked independently, but when they saw others engaged in them, even paratroopers who considered themselves particularly rugged individuals, knitted to exercise their hands and felt no embarrassment about it. Each ward was also provided with a pingpong table, a piano, and other recreational equipment. The whole point of the program was to make it as easy as possible for the patients to use their hands, and this they were far more inclined to do when they saw others doing the same thing.

It should be noted that this particular hand center was organized late in the course of the fighting, and that the bulk of the battle casualties had already passed through the hospital when it became operational. Moreover, evacuation had been so speeded up that there was relatively little time to work with the patients. It was possible, however, to show that the principle of concentrating patients with hand injuries in wards in which they could be kept *hand-minded* was perfectly sound and, in the event of another emergency, should be instituted at once. Further, every effort should be made to get patients with hand injuries into hand centers without delay, certainly within a week and preferably within a shorter period of time.

## The Hand Center at the 61st General Hospital

*(15th Hospital Center)*

The 61st General Hospital, Broadwell Grove, near Burford, Oxon, England, served the primary purpose of treating battle casualties evacuated to the United Kingdom from the battle fronts of Western Europe. Patients from all American Armies in Western Europe as well as British and French casualties were treated there. From 21 September 1944 to early November that year, the hospital received a large number of casualties from the airborne invasion

of Holland because of the hospital's location near Broadwell Grove airdrome. As in the previous hand center two wards and adjacent tents were designated for hand injuries [30] and wherever possible special equipment was obtained or made for these wards so that physical therapy and rehabilitation could be carried out on a group basis and individualized to fit the particular injury or condition. The ward personnel became more or less specialists in the particular condition they were treating, and were on the alert for the common avoidable complications and errors in treatment. Definite hour-to-hour programs were established so that a suitable portion of each day could be devoted to heat therapy, supervised activity and passive motion, purposeful exercise (such as preparation of surgical supplies, etc.), and recreational therapy.

The evolution of the program for complete segregation of patients was gradual and often difficult. Many times there were more cases of one category than the designated ward could handle. In general the plan worked out satisfactorily and hand and upper extremity cases were completely segregated in this hand center by mid-August 1944.

The majority of patients admitted to the orthopedic section, under whose aegis the hand wards operated, were battle casualties, and the most common cause of admission was compound fracture. Patients were received as early as 24 hours after wounding and as late as 3 weeks, the average being 4 days. The majority of the cases had had primary treatment in forward echelons consisting of supportive therapy, debridement, and plaster immobilization. Most of the cases were received in good condition and their wounds were clean. This hand center reported that fractures of the carpals and metacarpals represented 20 percent of the fracture admissions to the orthopedic section.[31]

### Clinical Measures

Every effort was made toward early closure of compound fractures, to protect such wounds from secondary infection and to suture the wound or replace lost skin by grafting at the earliest opportunity. Compound fractures were taken to surgery as soon as the general condition of the patient permitted. There, under aseptic conditions, the patient was anesthetized, the plaster removed, and the wounds inspected. Clean wounds suitable for closure were sutured or covered with split thickness or pedicle skin grafts. The fracture was then reduced and immobilized. A prophylactic course of pencillin and sulfadiazine was given to all patients so treated.

In the case of a severly injured ring and little finger, serious consideration was given to the advisability of early amputation.

Fractured metacarpals, if completely unstable and displaced, were manipulated and then held in finger traction for not more than 3 weeks. Traction

[30] Annual Rpt, 61st Gen Hosp, ETO, 1944. HD.
[31] Ibid.

alone, this hospital reported, did not always reduce these fractures. It stated that a marked permanent partial disability was to be expected in fractures of the metacarpals which extended into and disturbed the metacarpophalangeal joint. Experience has shown, the 61st General Hospital reported, that it cannot be assumed by neglecting the fractures in an injured hand and insisting on early active motion without splinting, that early complete function will result. Hands so treated frequently developed a severe chronic productive reaction about the fracture sites and injured joints which appeared actually to prolong convalescence. It would seem, the 61st General Hospital reported, that the ideal method would be to combine adequate temporary splinting of the fracture site with early active motion.

Severed tendons in clean wounds were sutured early and immediate active motion was started. Suture was done as late as 2 weeks after injury with very satisfactory results.

In summation this hand center reported that split thickness grafts offered quick coverage of large wounds, but the resulting surface was seldom satisfactory for the full-duty soldier; pedicle grafts were consistent in producing best results in covering compound wounds of the hand; that the time lag between wounding and adequate debridement appeared to be the greatest single factor in determining wound infection; and that rehabilitation of hands was a very slow process, in that improvement could not be seen from day to day, but rather from week to week and month to month.

## The Hand Center at the 217th General Hospital

*(814th Hospital Center)*

During the latter part of February 1945 the 217th General Hospital was designated as a hand center. The surgeons there reported early in 1945 that it had become clear that there were several aims which ought to be accomplished during the early care of the battle-injured hand, and that these varied in importance with the injury and the individual. They named the following: debridement; removal of foreign bodies; early closure of skin defects with the appropriate type of skin; amputation of functionally useless fingers; obtaining and maintaining of optimum bony position; treatment of infection; prevention of edema; maintaining motion in joints which are not or need not be immobilized, and prevention of peripheral vascular changes. These were accomplished by many means in the 217th General Hospital but especially useful were hot sterile saline baths with active motions when wounds were open, local penicillin, finger flap, skin transplants, Thiersch grafts, and various elastic-type exercisers which were made for the individual patient in the hospital brace shop.[32]

[32] Semiannual Rpt, 217th Gen Hosp, ETO, 1945–1, p. 9. HD.

### The Hand Center at the 1st General Hospital

*(815th Hospital Center)*

This hand center reported that the segregation of all severe hand injuries in one ward, under one team of medical officers, nurses, and ward men had constituted a definite advance in hand care. The principles of management emphasizing early active motion in extensive injuries, and with frequent debridements so that skin areas might be covered with grafts, had been followed. The main objective was to preserve function in the hands, the secondary objective was to prevent detrimental changes by means of early treatment. The results had been impressive. From 1 February to 30 June 1945 a total of 482 patients with hand injuries were received. Of these, 335 were battle casualties. Of the battle casualties, 65 percent were returned to duty, so it was felt the primary objective had been achieved. The second objective was at least partly met, for the operative records showed that 227 operations were performed, 81 percent of them plastic procedures.[33]

### The Hand Center at the 158th General Hospital

*(802d Hospital Center)*

The 158th General Hospital, Odstock, near Salisbury, Wiltshire, England, had experiences similar to those related.

However, in a report[34] made on that center's activities it was stated that after 4 months experience with the hand cases the conclusions were that although much good was done by concentrating them in a center in the way of securing early wound closure and prompt physical therapy, hand wounds still remained longterm problems of which only the surface could be scratched in the theater. Even the finger amputations they did on useless fingers in patients whom they felt sure they could return to duty under the allotted time were discouragingly slow in responding to rehabilitation. The problem was magnified by the fact that there were inevitably many patients with self-inflicted wounds among such a group, and that many of these were unrecognized as having been so incurred. It was impossible to separate them from the others, therefore, and they acted as a poor morale factor on the group as a whole.[35]

## CONCLUSIONS ON SPECIALIZED CARE IN HAND INJURIES

Hand centers did prove their value in the European Theater of Operations in the treatment of combat-incurred injuries. Certain conclusions concerning them are possible:

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[33] Semiannual Rpt, 1st Gen Hosp, ETO, 1945–1. HD.

[34] Annual Rpt, 158th Gen Hosp, ETO, 1945–1. HD.

[35] For another report on self-inflicted hand wounds, see first semiannual report of the 3d Auxiliary Surgical Group, 1945. HD.

1. *a.* Ideally, such a service should be under joint supervision of an orthopedic and plastic surgeon, each preferably having special interest and experience in hand surgery.

*b.* Nurses and enlisted personnel at a hand center should be specially trained in the care of hand injuries and should be kept on the hand service without rotation, since continuity of planned responsibility is desirable.

*c.* Physical and occupational therapy, which are of paramount importance in the treatment and rehabilitation of injured hands, should be on or near the wards set aside for a hand center.

2. Hand centers should be as near the front as circumstances will permit and evacuation of the wounded to them should be accomplished within 2 to 3 days after wounding. As a practical matter, however, patients with abdominal or head wounds, plus hand wounds, will never find their way to such installations. There is certainly, therefore, much to be said for immediate primary closure of certain selected hand wounds, after debridement in field or evacuation hospitals.

3. It has been suggested that in future wars a consultant should be appointed in each theater, whose sole responsibility would be the coordination and supervision of the care of hand wounds. If there is an abundance of trained surgeons available, perhaps a special consultant for each theater might be procured to provide better care for this small but important segment of the wounded.

## Experiences With Immediate Primary Closure of Hand Wounds

The delay in arrival at hand centers on the Continent and in the United Kingdom of soldiers with hand wounds became greater as the Armies advanced deeper into Germany. When it became apparent that 2 to 4 weeks might elapse from the time of wounding to arrival at a hand center, it was determined to try immediate primary closure of the wounds in the forward hospitals either by skin graft or suture, and to hold the patient nonevacuable for 5 days (see Appendix B).[36] This method was employed for only a short period before the termination of hostilities. It should be recorded that many surgeons opposed the plan, for reasons which they felt were sound: evacuation would be slowed up, and there were not available enough skilled surgeons to assign to forward area hand surgery.

Those who gave immediate primary closure a fair trial, however, reported brilliant results. At the 61st General Hospital, for instance, among some 25 patients whose hands had been closed in forward hospitals, the incidence of breakdown of wounds and infection was no higher than that encountered in soft tissue wounds elsewhere in the body.

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[36] First Semiannual Rpt, Surg Consultant, ETO, 1945. HD.

Toward the close of the war about half a dozen patients were received at the 129th General Hospital who had had primary closure of hand injuries in frontline hospitals. In a few cases primary closure had been combined with tendon suture. The number of cases was too small to warrant conclusions, but the few patients who were seen had beautiful anatomic results and excellent function. Slight as the experience was, it suggests that primary closure is a feasible and desirable method of handling combat-incurred injuries of the hand, though the results will naturally depend upon proper selection of cases and the skill of the forward area surgeons.

In May 1945 Lt. Col. William J. Stewart,[37] who served as assistant to the Senior Consultant in Orthopedic Surgery, as chief of the surgical service of a 400-bed evacuation hospital, and as chief of the surgical service of a general hospital, commented as follows on the new policy of immediate primary closure of hand injuries:

> As the evacuation hospital is now operated, it is necessary to keep up a very rapid rate, patients received, operated on, and evacuated after operation within 12 to 24 hours. If hand cases were held for 5 days, as has been suggested, the whole system would be in danger of stagnation.

A possible solution, he said, would be the establishment of a separate hand center in the Army area at the level of the clearing station, where hand injuries could be screened out of the line of evacuation and hand teams could be set up to perform competent early surgery. Patients could be held long enough to ensure a good end result without bringing about stagnation in the evacuation hospital. The policy of immediate primary closure would be safe under these circumstances, as it did not seem to be at that time. The patients then could be sent directly to hand centers in the communications zone. If the suggestion concerning hand centers in forward areas was not considered feasible, a far safer plan would be immediate debridement, the application of wet dressings, prophylactic chemotherapy, a 12-hour drying out period, and early delayed primary closure. Hand injuries would be far safer under the management of inexperienced surgeons by this plan than by the suggested plan of primary closure.

Maj. Ronald W. Adams of the 3d Auxiliary Surgical Group reported[38] his observations on a group of 50 primary closures done at the 91st Gas Treatment Battalion, where all patients with self-inflicted wounds were concentrated. His conclusions were that approximately half the wounds broke down, in whole or in part, after from 6 to 10 days. There were two severe infections. One type of wound in particular showed absolute lack of primary healing. This was the perforating wound of the palm produced by the high velocity bullet. In such a case the wound of entry is small while the wound of exit

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[37] Rpt, Lt Col W. J. Stewart to the Senior Consultant in Orthopedic Surgery, ETO, May 1945, sub: Hand injuries. Personal files of author.

[38] First Semiannual Rpt, 3d Aux Surg Group, ETO, 1945. HD.

is jagged, stellate, and disrupted. In general, the report concluded, the experiment failed to produce a significant improvement in wound healing or an earlier return of function. The report stated that the principles of hand surgery needing renewed emphasis which cannot be contravened with impunity are:

1. Meticulous early debridement, even if this takes several hours.
2. Wound to be left open for three or four days.
3. Immobilization with the simplest means possible. An elastic bandage is often better than plaster.
4. Early secondary (delayed primary—Ed.) closure, if necessary by means of a graft.
5. Physiotherapy and motion as early as the tenth day.

## Revision of Manual of Therapy

Meetings of the junior consultants in orthopedics were held on the Continent on 17 and 18 May 1945 and in the United Kingdom on 31 May 1945 to discuss methods which had been employed during the war and possible improvements in them.[39] The outcome of these meetings was the complete revision of the section of the *Manual of Therapy* [40] dealing with bone and joint injuries. This revision represents the final judgment of those who were responsible in the European theater for the management of these injuries during the course of the war and therefore stands, for the present, as the ideal method of treatment. These men, however, regarded it as quite possible that in a future war plaster for the immobilization of fractures for transportation would be displaced by a plastic which would be easier to apply and which might conceivably permit direct visibility of the underlying tissues.

The section in this revision dealing with hand injuries reads as follows:[41]

*Care of Hand Wounds*

1. *Introduction*

a. The hand is an extremely useful member of the body and a great disability results from its loss or its relative loss due to dysfunction. Experience in civilian and military fields directs that the early closure of wounds of the hand is essential to recovery of good function. In selected cases primary closure may be performed in Army installations. Good surgical judgment and technique must be exercised in doing this. Therefore this type of work should not be relegated to the untrained and unqualified surgeon. The following instructions are guides to be followed in early surgical treatment of battle wounds of the hand.

(1) *Surgical procedure*

(a) Thorough cleansing of the entire hand with soap and water is essential. This should include the clipping of the fingernails.

(b) Debridement must be thorough but done with meticulous care to avoid further damage. It is essential that the surgeon have an assistant. All devitalized tissues and

[39] First Semiannual Rpt, Orthopedic Consultant, ETO, 1945. HD.
[40] See footnote 8, p. 157.
[41] First Semiannual Rpt, Orthopedic Consultant, ETO, 1945, Exhibit C, sec. VIII.

foreign bodies must be carefully removed. Hemostasis must be complete and should be accomplished by ligation of all severed vessels with the finest ligature available. (Silk, cotton or chromic cat gut.) Do not remove bone fragments. Only that portion of tendon which is macerated should be excised. The suture of tendons at this time is not indicated.

(c) Closure should be performed with widely placed interrupted sutures without tension. Drains should not be inserted into the wound. If it is impossible to close the wound without tension, approximate the skin edges as closely as possible, with a few well placed stay sutures. It is important that bone and tendons be covered by soft tissue wherever possible. In a few selected cases, a thin split skin graft may be taken to cover large denuded areas.

(d) *Amputation of Fingers.* Amputate only those fingers which are irretrievably destroyed. To aid in the closing of the remainder of the hand, sometimes it is possible to save some skin from a finger which must be amputated. It is important to salvage every possible portion of the thumb.

(2) *Dressings*

(a) Dressings will be applied snugly but not tightly and will adequately cover the entire wound.

(b) *Immobilization.* Hand will be supported on a molded anterior plaster splint with the hand and fingers in the position of function, i. e., the wrist in slight dorsiflexion the fingers flexed approximately 30° to 40° at all joints and the thumb slightly flexed and in moderate adduction and apposition.

(3) *After care*

(a) If primary suture of a hand is done, the patient must be held a minimum of five days for close observation.

(b) The hand will be kept elevated continuously during this period to minimize swelling and edema.

(c) Penicillin therapy is to be administered throughout the entire period.

(d) The primary dressing should not be disturbed until the fifth day unless there is evidence of sepsis. If fever or increase of pain occurs, the wound should be inspected and if infection is present, remove enough sutures to allow for adequate drainage.

(e) Change dressing on the fifth day and inspect the wound under aseptic conditions. This is to avoid placing the occasional case in the chain of evacuation who may have a low grade infection which had not been picked up by clinical manifestations.

(f) Instruct patient to keep hand in a position of elevation during his evacuation.

## SUMMARY

From the foregoing it can readily be seen that the early treatment of gunshot wounds or battle injuries involving the hand underwent a considerable evolution during the 11 months of combat in the European theater. This theater, with its 4,000,000 troops and some 260 hospitals, occupied a relatively small and compact area, with unusually fine facilities for transportation.

In theory, the wounded hand could conceivably be afforded ideal treatment in the Army hospitals of the forward zone. In the same way, the slightly wounded soldier who could be promptly returned to duty should receive high priority in surgical treatment. From every utilitarian standpoint of winning battles the surgeons should concentrate on these cases. In practice it did not work out that way. During the stress of combat, the most seriously injured, least transportable patients received preferential treatment. The major efforts

of the Army surgeons were constantly expended on their behalf, often when they were apparently irretrievably injured. They were never abandoned while there was any chance of saving life or limb. That knowledge prevailed among the United States Army troops and was of major importance as a factor in morale.

Because this conflict between the hard necessities of war and the instinctive humane practices of the Army surgeons was always resolved in favor of humanity, hand injuries were given less attention than they should have received in the forward areas, where the type and quality of the initial treatment might determine the end results of these injuries. It was a fundamental error to regard hand injuries as minor surgery but even when there was a full appreciation of the possible disability resulting from them, combat circumstances often made it inevitable that wounded hands should be bypassed or should be referred to less experienced surgeons for care.

Very little has been said heretofore regarding soldiers with multiple wounds. A soldier might, and often did, enter an evacuation or field hospital with compound fractures of the femur, tibia and fibula, and an abdominal wound as well as a wounded hand. The question of priority of wounds in such an instance is a nice one and it must be confessed that the hand might receive lower priority than ideal hand surgery would suggest.

During the early days of the war, theater holding policies made it impossible to keep the wounded in Continental hospitals long enough to carry out anything approaching the ideal type of care essential for good results in hand surgery. At the time of the Battle of the Bulge, all hospitals, both on the Continent and in the United Kingdom, were cleared of every remotely transportable patient to prepare for an unknown number of casualties. This meant the transfer to the Zone of Interior of many patients who could otherwise have been returned to duty in the theater, and it also meant that some borderline patients were evacuated whose ability to stand the trip might be in question.

Repercussions concerning the patients in the last-mentioned group were not long in reaching the European Theater of Operations, and criticisms for sending them home were received. The decision to return these patients to the Zone of Interior, however, must be considered as part of the same calculated risk that allowed the German Army to initiate the Battle of the Bulge.

The management of injuries of the hand can best be summed up in the words of Brig. Gen. Elliott C. Cutler, Consultant in Surgery for the European Theater of Operations, who wrote:[42]

> During the war, as increased numbers of bad hands were seen, we were forced to the conviction that specialists should care for these and in certain selected hospitals where there was a proper liaison between able surgeons, orthopedic surgeons and plastic surgeons, all bad hands were concentrated. A study of the work at these hand centers in our rear areas convinced me that a better result could be achieved if more

[42] Ltr, Brig Gen E. C. Cutler, Consultant in Surgery, ETO, to Surgical Consultant, 1st SvC, 30 Nov 45, sub: Hand injuries, ETO. HD: 730 ETO.

definitive [treatment] were begun in the forward areas. We finally therefore set up a directive which I presently took to the consulting surgeons of our four armies, asking them that the mutilated hand be given special care in the field and evacuation hospitals, that its care be given to the best surgeons, that these surgeons utilize (A) thorough debridement; (B) conservatism as regards amputation, and (C) that when it seemed possible, the wound be closed in the forward area. This was to do away with a multilation caused by packing etc., and finally to make primary closures safe we decreed that the closed injured hand could be held in the forward hospitals 3 to 7 days, just as we held the closed head, the closed chest and the closed belly. Unfortunately this plan was not in effect for a long enough time for us to amass any great amount of experience. . . . I am convinced that this is the final step forward in a tremendous improvement which should have given both better function and less amputation.

## CONCLUSION

In World War II surgeons with specialized training in hand care were not available until hostilities were over, and most of them learned their hand surgery in the Zone of Interior, where they continued to perform magnificent feats of surgical repair of damaged hands up to 2 years or more after hostilities had ceased.

A great deal was learned about the problems of hand surgery in a theater of operations by those who were privileged to serve in the European theater. Most of the experience was gained the hard way—through trial and error. There was, however, a steady and encouraging progress in the care of combat-injured hands which should not be forgotten should another similar emergency arise.

## APPENDIX A

HEADQUARTERS

EUROPEAN THEATER OF OPERATIONS

UNITED STATES ARMY

Office of the Chief Surgeon

8 November 1944

CIRCULAR LETTER NO. 131

*Care of Battle Casualties*

The following instructions are supplemental to Manual of Therapy ETO, 5 May 1944; Circular Letter No. 71, 15 May 1944; and Circular Letter No. 101, 30 July 1944, Office of the Chief Surgeon.

1. *Treatment of Wounds of Bones and Joints.*

* * * * * * *

b. *Immoblization of fractures for evacuation.* Field and Evacuation Hospitals and any type of medical unit acting as a "transit" hospital will prepare fractures for early evacuation with comfort and safety to the patient. They will not be responsible for the anatomic reduction of these fractures.

* * * * * * *

(6) *Fractures of metacarpals and phalanges* should be loosely bandaged with sheet wadding and ordinary gauze bandage and a sling provided. A careful, gentle

scrubbing of these wounded hands with soap and water will definitely minimize the chance of infection.

* * * * * * *

c. *Treatment of wounds of bones and joints in General Hospitals. . . .*

* * * * * * *

(3) *Compound fractures of the hand and fingers* should be treated primarily as soft tissue injuries. In no case should such fractures of the hand and fingers be immobilized over two (2) weeks. A useful hand with imperfect bone alinement is far more desirable than a stiff hand with perfectly reduced fractures.

* * * * * * *

f. *Injuries of the hands.* Compound or simple fractures of the hands and fingers present very special problems, which are frequently badly handled. Patients with these injuries would probably be better treated if they were grouped together within each hospital and a definite plan of treatment carried out. The danger of prolonged immobilization applied to the hand and fingers cannot be overemphasized. In general, wounds of the hands and fingers, accompanied by compound fractures, should be treated as soft tissue injuries, with every attempt made to close the wound by secondary suture or skin graft, and early active motion insisted upon. When tendons and bone fragments are exposed by extensive loss of soft tissue, a pedicle skin graft may be required and the patient should be promptly transferred to the nearest designated hospital for specialized treatment by Plastic Surgery. In selected cases, if skeletal traction is required for one or two digits to secure reduction and immobilization of the metacarpal fractures, it should be applied through the proximal phalanges and constant effort should be made to secure early active motion of all fingers. Such traction should not be employed for a period longer than 2 weeks, and the remaining phalangeal or metacarpo-phalangeal joints will not be immobilized. *In no instance should pulp traction be employed.* Necrosis of fingers has been noted following this form of traction.

Effective active exercises and physiotherapeutic supervision should be instituted on these hand injuries from the beginning, and be pursued during their entire period of hospitalization. Immobilization of fingers in full extension may result in permanent disability.

Amputations of hands or fingers should be performed *only* where there is *no* possibility of restoring some useful function or when circulatory loss has resulted in complete necrosis of the part. These amputations should always be at the most distal point possible. Salvage of any portion of the hand is of the utmost importance, since an upper extremity prosthesis is not in any sense to be considered as an adequate substitute for a hand.

The single exception to this rule of conservation in regard to amputations of the fingers and hand, is a compound fracture of one digit with destruction of the flexor and extensor tendons. A prompt amputation of this digit and early active motion of the rest of the hand and fingers will insure a rapid convalescence and restoration to duty status. This problem of hand and finger injuries must be given serious and thoughtful consideration. It is extremely difficult and sometimes impossible to overcome the stiffness of hand and fingers which results from unwise and unnecessary immobilization.

2. *Neurosurgical Problems.*

* * * * * * *

(2) All major nerve injuries complicated by fractures should have early closure of wounds and adequate splinting without attempting to secure anatomic reduction of the fracture. This plan permits early suture of the nerve with later reduction of the fracture by open operation if necessary. The restoration of length before the nerve repair is accomplished, may defeat the possibility of end-to-end suture of the nerve.

* * * * * * *

# APPENDIX B

HEADQUARTERS

EUROPEAN THEATER OF OPERATIONS

UNITED STATES ARMY

Office of the Chief Surgeon

5 May 1945

CIRCULAR LETTER NO. 39

SECTION I. *CARE OF HAND INJURIES*

1. *Introductory:*

a. Experience in civilian and military fields directs that the early closure of injuries to hands is essential to recovery of good function. The great vascularity of the hand, as in the face, makes closure of such wounds desirable.

b. In the rear areas careful studies on improving the surgical care of the hand in hospitals specially equipped for this field of surgical treatment have revealed that further progress will only occur when improvement is made in the initial therapy. The following instructions are guides for the early surgical treatment of hand injuries.

(1) *Surgical Procedure:*

(a) Thorough cleansing of entire hand and nails is essential. Nails must be clipped.

(b) Debridement will be meticulous, including removal of all accessible foreign bodies. Skin must be conserved. Tendons may be sutured where loss of substance is minimal.

(c) Primary closure is to be performed. Sutures will be widely spaced. Drains are not to be inserted. Where closure by suture without tension is impossible, split thickness skin grafts will be applied immediately.

(d) *Amputations:* Conservatism will rule. Amputate only fingers that are irretrievably lost. To aid in closing the remainder of the hand, save the skin of such a finger if it is viable. Wherever possible, the thumb or any part of it will be saved. The 4th and 5th fingers can be most readily spared. A stiff 4th finger jeopardizes the use of the remaining fingers. These amputations will be loosely closed primarily.

(2) *Dressings:*

(a) Dressings will be snug but not tight. They will adequately cover the entire area.

(b) *Immobilization:* Hand will be supported on a moulded anterior plaster splint with the hand and fingers in the position of function, i. e., the wrist in slight dorsiflexion, the fingers flexed approximately thirty to forty degrees at all joints, the thumb adducted and slightly flexed.

(c) The hand must now be kept in an elevated position to prevent edema which will drastically interfere with subsequent function of the hand and fingers.

(3) *After Care:* The wound will be inspected only if local or generalized signs or symptoms of sepsis appear. If there is evidence of infection, remove a sufficient number of sutures to permit drainage. Do not insert drains. Apply heat (dry heat preferable) and continue elevation. Force penicillin therapy.

(2) *Evacuation Policy:* To carry out this primary closure of wounds of the hand, these cases must be held as non-evacuable for a *minimum of five (5) days.*

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# APPENDIX C

HEADQUARTERS

EUROPEAN THEATER OF OPERATIONS

UNITED STATES ARMY

APO 887

17 May 1945
ECC : hjc : PS

Lt. Col. P. S. Foisie, M. C.
129th General Hospital
APO 209

Dear Colonel Foisie:

I have been shown your new brochure on the hand. It is fully as valuable and even better illustrated than the one on fractures, which was copied for distribution throughout the Theater.

I would like to extend my congratulations for having done such a splendid piece of work, and hope you will add my thanks to Sergeant William Pitney. You and he are a good team, for you have been able to use Sergeant Pitney's unusual abilities in drawing to encourage those who have been damaged and to give them high hopes in their hour's need.

We will send a copy of the booklet back to the Surgeon General's Office and hope they may make some use of it in the hand centers in the Z. I.

Sincerely yours,

PAUL R. HAWLEY
Major General, USA
Surgeon, Com Z.

CHAPTER V

# Hand Injuries in a Debarkation Hospital (Letterman General Hospital)

*Donald R. Pratt, M. D.**

Over a 2-year period (1943–44) the hand injuries received at Letterman General Hospital, which was serving as a debarkation hospital from various theaters of operations, presented numerous differences in condition and progress, usually to be explained by factors within the theaters.

## ALASKAN THEATER

The first casualties received at Letterman General Hospital had been injured in the Attu campaign. They were received in the Zone of Interior within 2 or 3 weeks after the initial injury. Evacuated to hospital ships or naval transports shortly after being wounded, their wounds had been treated promptly and splintage was adequate. Moreover, the men were in good general physical condition and the nutrition of their hands was good. As a consequence, serious infection was insignificant, and most wounds were satisfactorily closed.

## PACIFIC AND CHINA-BURMA-INDIA THEATERS

Casualties received from the Pacific, Southwest Pacific, and China-Burma-India theaters showed the effects of prolonged transportation and general debilitation. The superimposed effects of malaria, dengue fever, malnutrition, and the altered metabolic rate associated with combat under tropical conditions were evidenced in delayed wound healing and sluggish infection. The enormous distances of the evacuation chain made inevitable a long lapse of time between wounding and return to the Zone of Interior. When in the later months of 1944, air transportation was employed from such places as Guam and Saipan, this interval was materially reduced.

During the early months of combat in the Southwest Pacific theater many patients with hand injuries had been treated with the banjo splint or with flat, straight board splints applied to the hand and wrist in the position of nonfunction. Both methods are equally undesirable and were responsible for many disabled hands. Many of the casts applied in the zones of communication did not adequately maintain the palmar arch, the opposed thumb, and the dorsiflexed wrist, with the result that flat hands and other deformities occurred. A

*Assistant Clinical Professor of Surgery, Stanford University Medical School. Formerly Lt. Colonel, MC, AUS.

large percentage of the casts worn by these casualties had to be changed on the debarkation service of Letterman General Hospital as soon as the patients were received.

The initial dressings of hand injuries in the China-Burma-India theater were sometimes applied by aid men a few minutes after wounding and sometimes 12, 24, or 36 hours later at a casualty station, depending upon the terrain. Initial surgery consisted of debridement and immobilization with plaster in the position of function. Little or no reparative surgery could be attempted because of the general debility of the patients and the stress of air evacuation to rear echelon hospitals.

During certain campaigns in the China-Burma-India theater there were unusually long delays in the initial dressing and treatment of hand injuries. Patients who had suffered such delays were likely to present chronic infection and extensive cicatricial contractures. These deformities were particularly evident in Air Force casualties who had suffered extensive burns of the dorsum of the hand and forearm and who frequently presented typical claw hands and stiff interphalangeal joints.

## MEDITERRANEAN (NORTH AFRICAN) THEATER

Casualties received from the Mediterranean (North African) theater presented fewer cicatricial deformities and fewer chronic infections of the hand than casualties received from the Far East. The majority had been treated with early dressings and rest by proper splintage in the position of function (Figs. 71–80), while early reparative surgery had also been done. Infection

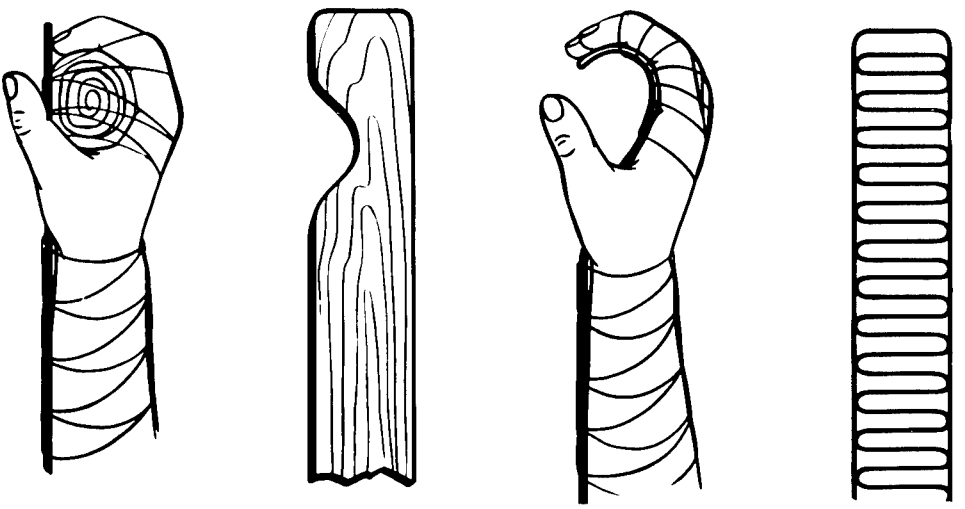


*Figure 71. Board and wire splints satisfactory for temporary use. Wrist is cocked up, fingers are flexed, and thumb is free.*

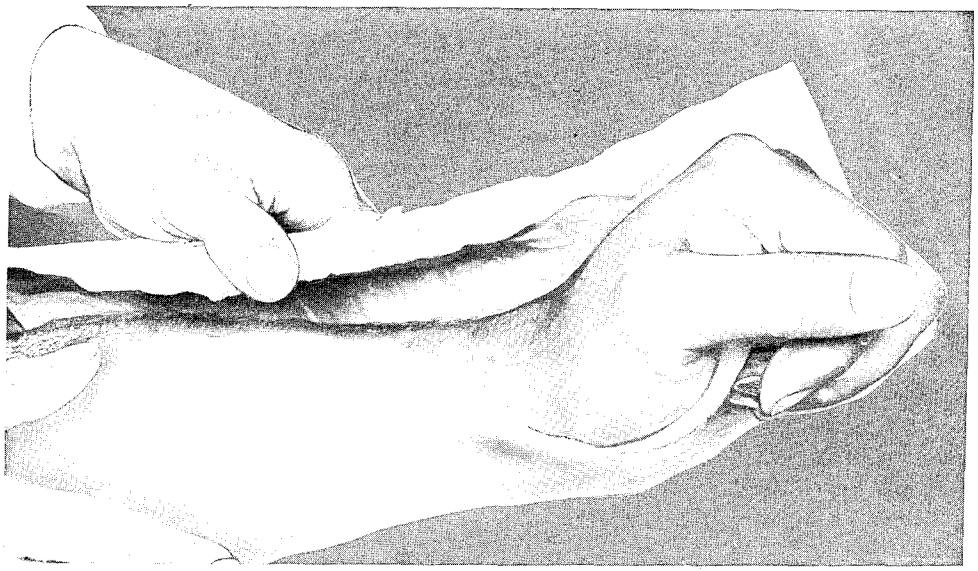


*Figure 72. Plaster slabs applied for form-fitting cast, bivalved to provide space for swelling. Fingers and thumbs are free to move. Note wax paper separating slabs.*

was therefore greatly reduced and tendon and nerve sloughs were correspondingly fewer. Distances and transportation were also problems in this theater, and even when air transportation was introduced many weeks often elapsed before the patients were received in the Zone of Interior.

A rather large number of patients were received with granulating burned areas on the dorsum of the hand, for which skin grafting was necessary. Late in 1944 specific attention was given in the theater to early reparative surgery and to the position in which hand injuries were splinted. As a result, marked improvement was observed in the condition in which these so-called minor injuries were received in the Zone of Interior.

## EUROPEAN THEATER OF OPERATIONS

In the European Theater of Operations, shorter distances and greater facilities for evacuation and transportation favored the condition of all casualties, including those with hand injuries. In this theater air transportation was usually employed promptly to convey the wounded to fixed general hospitals. Moreover, the mobilization of specialists afforded in large numbers of cases opportunities for the employment of reparative surgery of a high quality.

Casualties in the European theater were usually treated at aid stations within 30 minutes to 2 hours from the time of wounding. Patients with hand

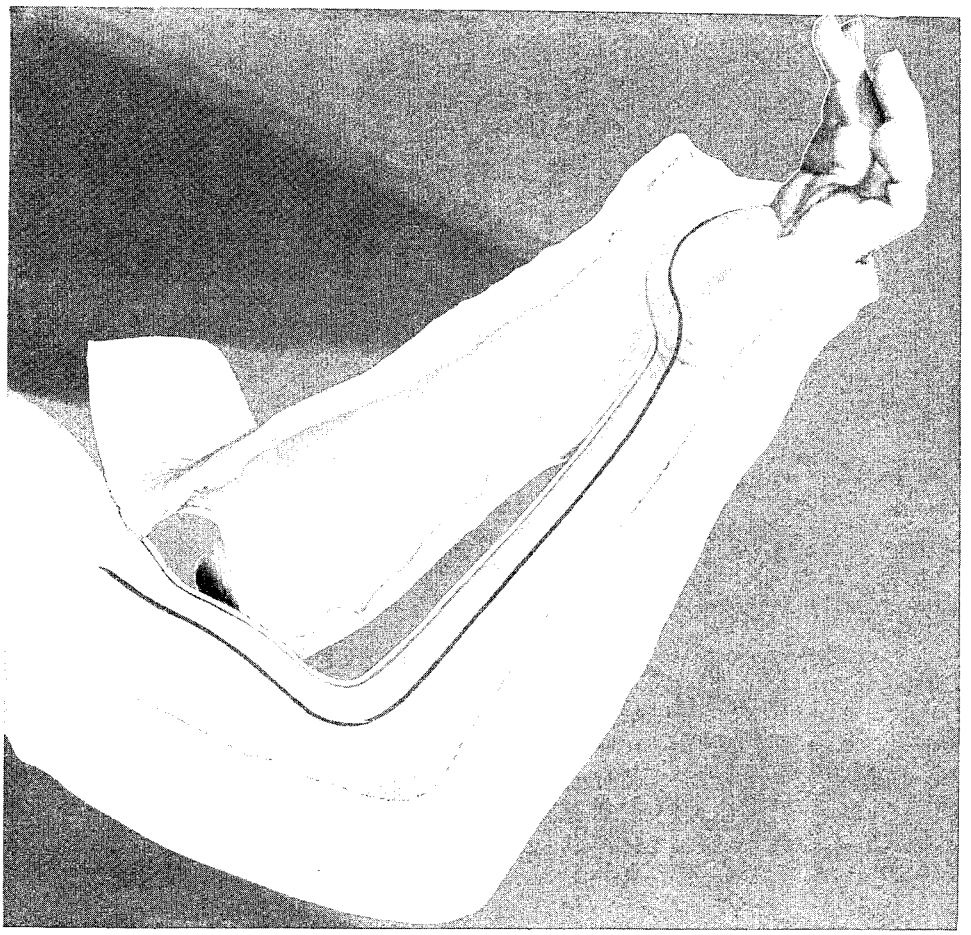


*Figure 73. Properly bivalved plaster cast for forearm and upper arm. Note complete separation. Dangerous, inadequate line which does not relieve anticubital pressure to avoid Volkmann's ischemic contracture, is shown in ink.*

injuries were treated as walking-wounded cases unless there was evidence of shock, vascular damage, or associated injuries; in such cases they were treated as litter cases and received priority in evacuation. The initial treatment in aid stations for wounds of the fingers and hand was the application of a cock-up wrist splint and some form of traction, with particular attention to maintenance of the position of function. In the later stages of combat in France and Germany, aid stations were able to maintain ambulance communication with the front lines, and in many cases evacuation by ambulance or jeep reduced in time between wounding and arrival at the aid station to a matter of minutes. Specific treatment was therefore promptly supplied in collecting and clearing

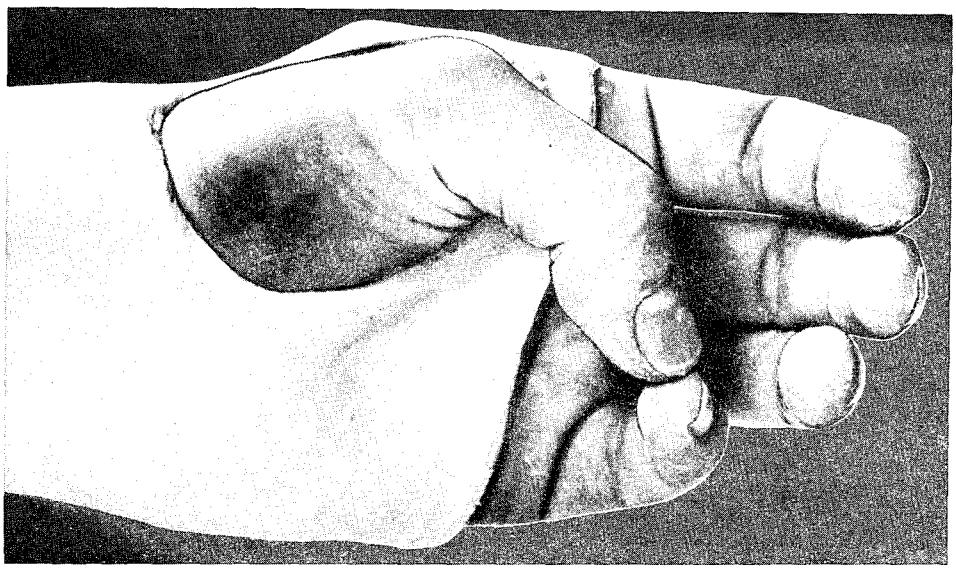


*Figure 74. Plaster cast to immobilize wrist, ending at distal palmar crease in thick rather than feather edge. Note arch of palm and strong, narrow band across web of thumb. Note also that thumb is free to oppose little finger.*

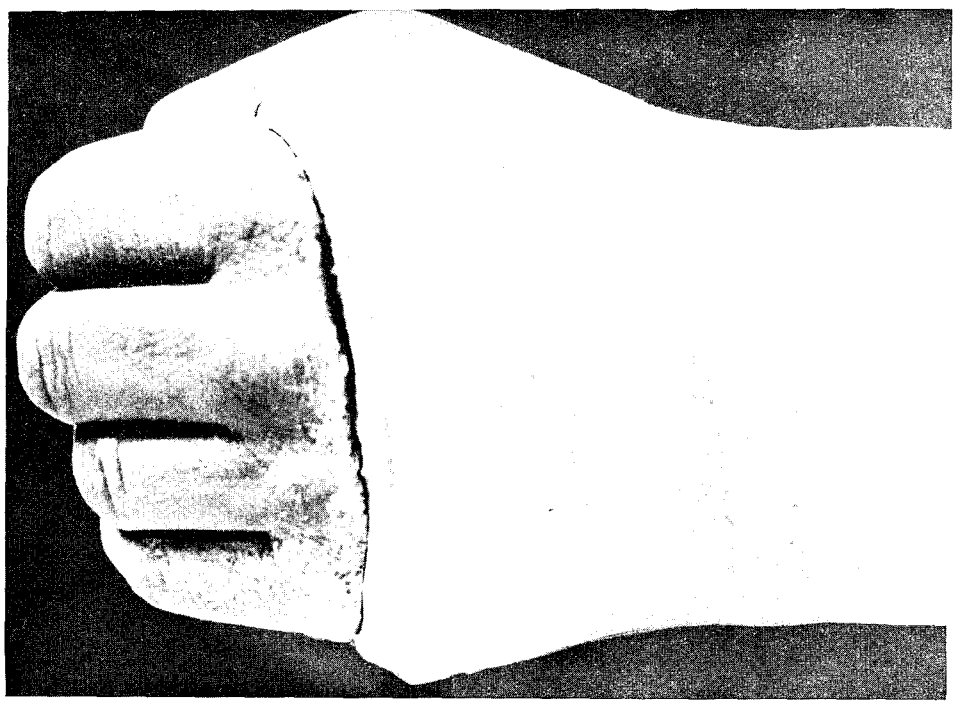


*Figure 75. Plaster cast covering dorsum of hand and extending to knuckles. Swelling of hand does not occur with this type of cast.*

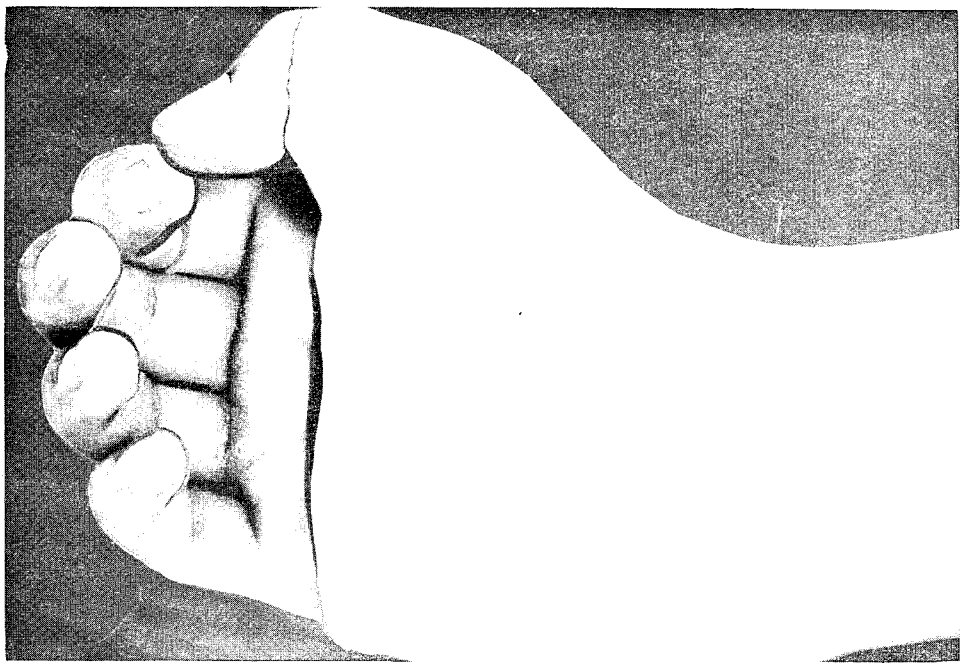


*Figure 76. Plaster cast for immobilization of carpal scaphoid, extending just to distal palmar crease. Note molded arch and thick edges of cast. Note also that thumb is opposed to index finger and that all finger joints and the distal joint of the thumb are free to move.*

companies, and casualties were often received at evacuation hospitals within 4 to 8 hours after wounding. Initial surgery was carried out within 12 hours of injury and was followed by evacuation by air to fixed general hospitals in the communications zone, where reparative surgery was done between the fourth and seventh days. Speed of evacuation was a prime factor in the treatment of men who received hand injuries in the European theater.

The majority of hand injuries received at Letterman General Hospital from the European theater were covered with thick split skin grafts or pedicle flaps. The first phase of the reconstruction problem had therefore been started before the soldier was received in the Zone of Interior. Few of these patients presented deep cicatrices, latent infection was minimal, and as a rule the position of function was maintained.

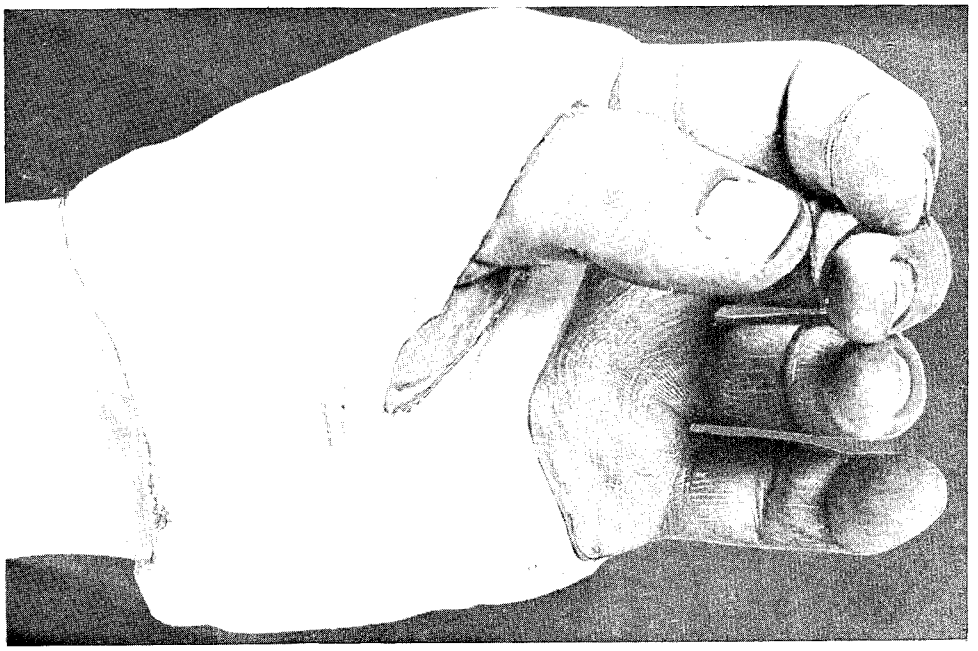


*Figure 77. Plaster cast to support thumb in paralysis of opponens pollicis.*

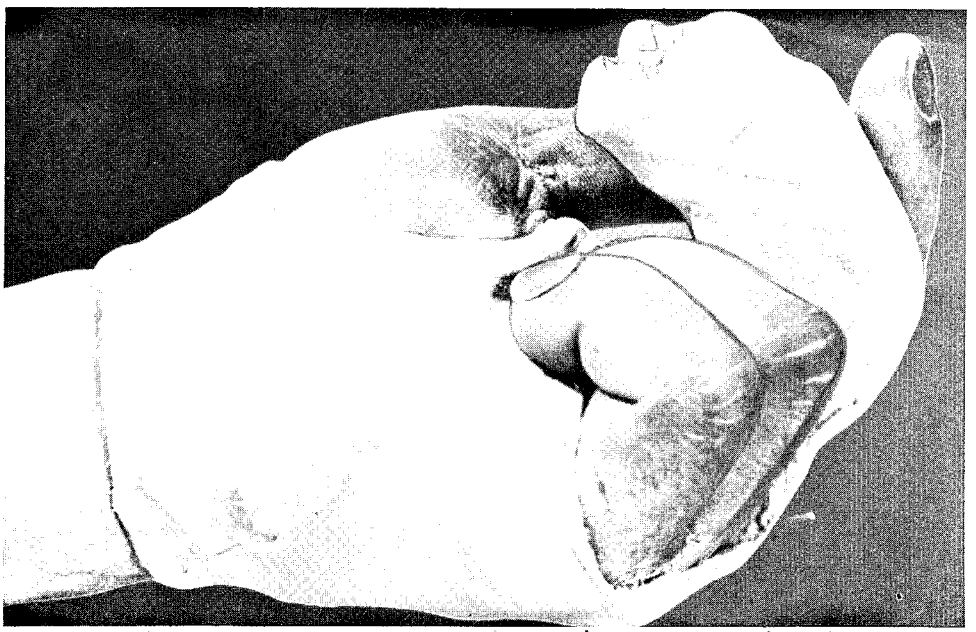


*Figure 78. Cast to immobilize one finger. Note full flexion of adjacent fingers and slightly flexed proximal joint of injured middle finger.*

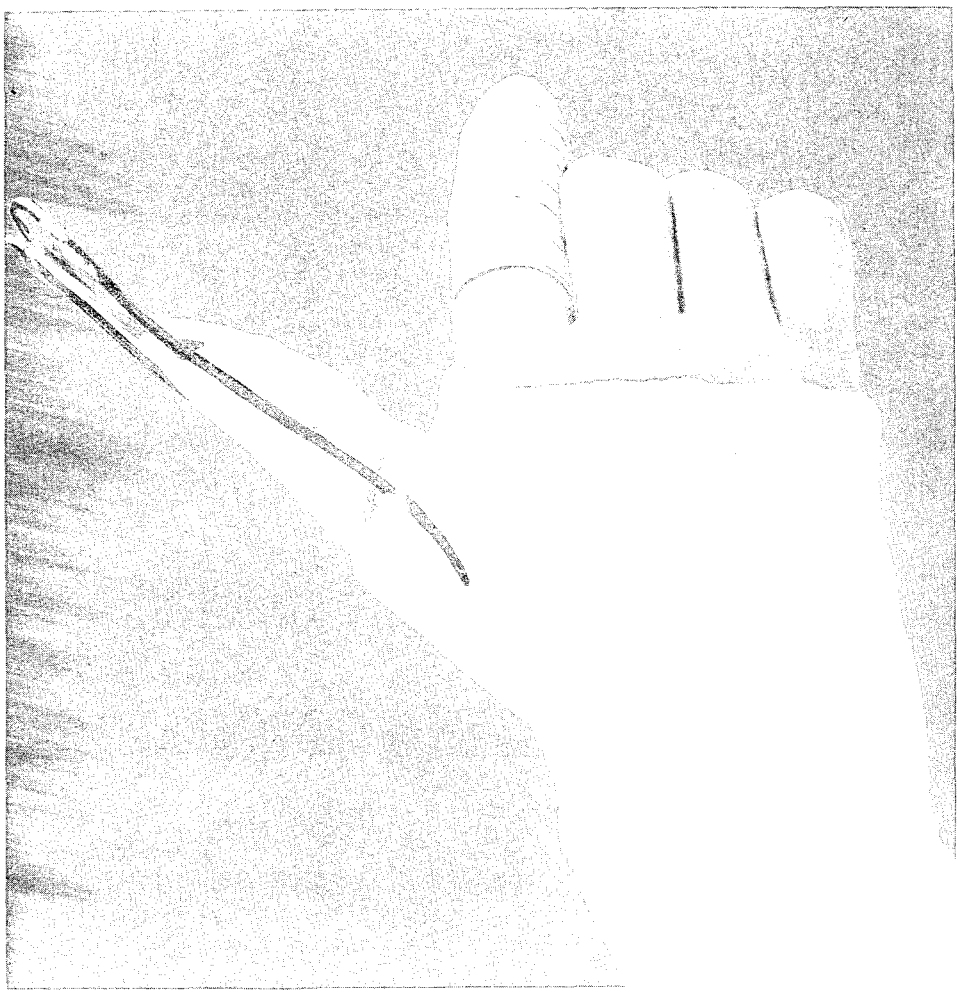


*Figure 79. Skin traction applied to thumb by spiral adhesive or skin glue method.*

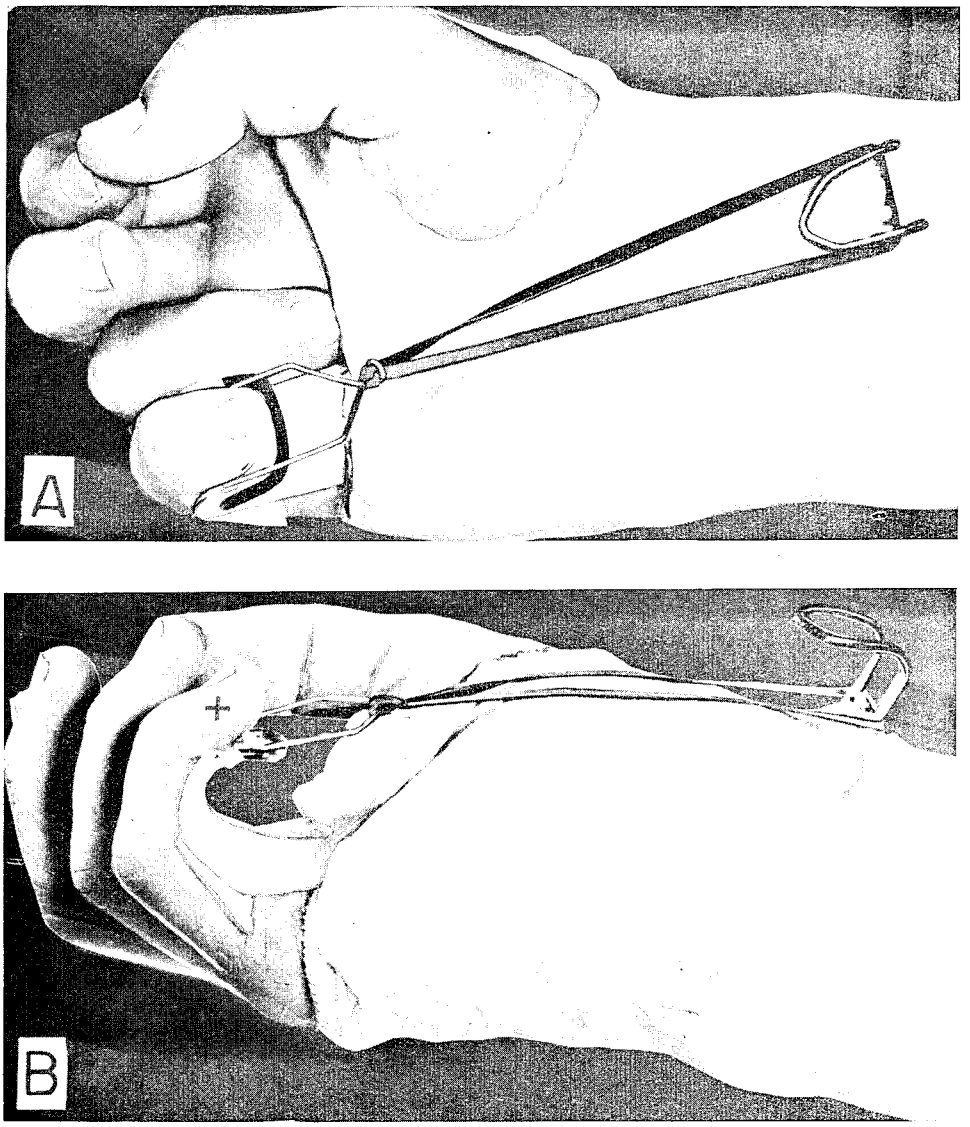



*Figure 80. Stirrup type of finger traction. A. Anteroposterior view showing finger pulled in direction of tubercle of carpal scaphoid. Adjacent fingers and thumb are free to flex and extend without limitation and palmar arch is maintained. B. Lateral view. Traction pin penetrates finger pulp at x.*

# *HAND SURGERY AT NINE HAND CENTERS IN THE ZONE OF INTERIOR*

CHAPTER VI

# Hand Surgery at Newton D. Baker General Hospital

*S. Benjamin Fowler, M. D.**

## EVOLUTION OF THE HAND SECTION

Patients in need of reconstructive surgery of the hand were first received at the Newton D. Baker General Hospital in August 1944. There was no general policy for their management, and they were admitted to the plastic, orthopedic, or neurosurgical sections, according to the component of the hand most seriously injured. By 1 December 1944, when more than 100 patients with injured hands were in the hospital, it became mandatory that some general policy of management be instituted.

It was decided after a conference participated in by the staffs of the orthopedic and plastic surgery sections and the chief of the surgical service (1) that all patients with serious hand injuries be segregated; (2) that they be placed under the overall control of the orthopedic section but classified as plastic cases for record purposes; (3) that a consultation system be inaugurated and each patient studied by orthopedic, plastic, and neurosurgeons, who would jointly outline management.

The following categories were regarded as in need of reconstructive surgery of the hand:

1. Those patients with skeletal deformities or tendon defects.

2. Those patients with nerve lesions who presented (a) lesions below the wrist, (b) irreparable lesions requiring tendon transfers to motivate the wrist or digits, and (c) lesions in the forearm combined with soft tissue or skeletal defects.

3. Those patients with deformities of the hand and forearm which required more than skin replacement.

The closest possible cooperation existed among orthopedic, plastic, and neurosurgical staffs, and in spite of technical difficulties every problem involving a combination of injuries was managed in consultation by representatives of all three.

By March 1945, the number of patients had so increased that the system set up in December 1944 had become unwieldy. Approximately 45 percent of all admissions to the plastic surgery section were hand cases, and over the preceding 8-month period the ratio of hand to general plastic patients had been roughly 4:5.

In April 1945 a full-time plastic surgeon was assigned to the hand subsection, obviating the necessity of transferring patients for skin grafting. His addition to the staff removed certain other difficulties. Confusion had

*Orthopedic Surgeon. Formerly Major, MC, AUS.

frequently arisen regarding subsequent operations on various patients, and the plastic work on the skin had often proved inadequate; underlying pathologic processes were frequently not adequately exposed and recorded by plastic surgeons, whose interest was primarily in skin defects. Effort was made to reduce the number of operations to which the patient would be submitted. A neurosurgeon, therefore, occasionally sutured a peripheral nerve while a bone or tendon deformity was being corrected. A plastic surgeon might prepare a skin flap while the orthopedic surgeon dissected out the defect.

All nerve sutures in the forearm were originally handled on the neurosurgical service, tendon repairs being a separate procedure. Later, combined nerve-tendon injuries became an exclusive problem for the hand service. This was a wise change, since it did away with the necessity for two separate operations through the same incision, each of which left its quota of permanent scar tissue.

Addition to the staff of a full-time plastic surgeon solved some, but not all, of the difficulties associated with the management of hand injuries. As the number of hand injuries increased, it was the general opinion that these patients could best be handled on a separate section devoted entirely to hand surgery, where they could be under the management of men whose entire time was devoted to this work and where other factors would also be more favorable. It seemed illogical, since analyses showed that not more than 20 percent of the patients required major plastic procedures, that patients whose predominant disability was musculoskeletal should be treated on the plastic service.

The special section for hand surgery began to function 1 August 1945, and certain benefits promptly derived. The delay previously experienced as patients were transferred from section to section for treatment was eliminated. Splinting, which had previously been somewhat neglected, now received its proper share of attention. Conservative measures of treatment were followed through more efficiently.

## INCIDENCE

Between 1 January and 31 July 1945, 409 operations on the hand were performed, but how many patients with hand injuries were admitted during that time is not known since these patients, for purposes of record, were classified as admissions to the plastic service. From 1 August through 30 November 1945, when the hand service was operated as a special section, it received 334 new patients and on it 442 hand operations were performed. The monthly census ranged from 523 in August to 492 in November.

## QUALIFICATIONS AND TRAINING OF PERSONNEL

In December 1944, following the first conference on the management of hand injuries at Newton D. Baker General Hospital, patients with these injuries

were placed in charge of an orthopedic surgeon whose training qualified him for certification by the American Board of Orthopaedic Surgery; he had a special interest in hand surgery. Until April of the following year no qualified assistant was available. A general surgeon with some training in plastic surgery was then assigned to the service on a part-time basis. Shortly afterward another officer, well trained in general and plastic surgery, with additional experience in hand surgery in the Army, was also assigned to the hand section. After a period of intensive training on the hand service both of these officers were competent to run their own operating rooms.

On 1 August 1945 an officer certified in general surgery, with 5 years of training under Dr. Sterling Bunnell, was appointed as chief of the hand service. This was the first formal appointment to that position and this officer remained in charge until November 1945 when he was succeeded by a similarly qualified officer with orthopedic training.

Until November 1945 there was a constant shortage of personnel on the hand section, chiefly in the category of ward officers; the proportion of ward officer to patients was never less than 1:100. In November the situation was alleviated by the assignment to the service of 5 officers, 4 of whom with internships only, but 1 of whom had had, in addition, a surgical residency of 1½ years. With this increment of personnel, it was possible to undertake more deliberate training in hand surgery. From the beginning, every endeavor had been made to train men assigned to the service by instruction during ward rounds as well as in the operating room, to which each officer was assigned for 4 half days weekly.

## RECONSTRUCTION OF HANDS

### Skin Replacement

The management of skin and soft tissue defects of the hand was the special responsibility of a single qualified officer on the hand service. If the deeper soft tissues were not too severely damaged, split thickness skin grafts were used almost universally on the dorsum of the hand and the digits. In two cases, tendon grafts were placed beneath split skin grafts on the dorsum of the fingers; one operation was successful, the other not. In several instances in which the skin on the dorsum was inadequate for flexion, a transverse incision was made directly over the knuckles, capsulotomy was done on the metacarpophalangeal joints, and a split thickness skin graft applied over the defect with the fingers flexed. These patients did remarkably well and could not have benefited more if they had been treated by pedicle grafts. Some full thickness skin grafts were used in the palm and on the palmar surface of the finger when no deep surgery had to be done in the vicinity.

As the months passed there was considerable improvement in the management of pedicle grafts. At first, almost all such grafts were of the open type,

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presenting broad granulating surfaces in which infection occurred to a greater or lesser degree. They constituted a considerable problem from the standpoint of dressing, and healing of the proximal portion of the flap was often by second intention. Later, the open type of graft was discontinued. It was the general opinion that hands treated by closed pedicle flaps in which infection had not developed, loosened up more rapidly and that the stiffness observed when open pedicle grafts were used, never appeared.

Pedicles were most often and most satisfactorily closed by the application of split thickness skin grafts over the defect. In certain instances, however, the surgeon constructed an abdominal tube, one end of which was immediately transplanted (Fig. 81). This technique furnished the advantages of the skin tube combined with those of a pedicle flap. Results were excellent and the technique constituted a real advance over earlier methods.

## Osteotomy and Bone Grafting

Fractures of the phalanges and metacarpals, with malunion or nonunion, were common, and usually quite disabling (Fig. 82). Bone grafts were inlaid into the metacarpals with fixation by Kirschner wires which transfixed the grafts and usually the distal portion of the metacarpal. Almost universally successful, this procedure permitted the surgeon to combine capsulotomy of the metacarpophalangeal joints with bone grafting of the metacarpal, saving the patient an additional operation. Fixation pins were also used for fractures (Figs. 83 and 84).

The donor area for bone grafts of the metacarpal was almost always the upper end of the tibia. Grafts were removed by means of a motor saw. Union was invariably so advanced within 6 to 8 weeks that external fixation could be discontinued. Nonunion and infection were seldom observed when this technique was used. The fixation pin occasionally migrated (Fig. 85) but was usually removed without difficulty. All pins were fairly loose at the end of 6 weeks and could be withdrawn by making a nick in the skin and simply pulling them out. Originally transfixion pins were left sticking out through the skin, but there was usually drainage about them and the possibility of the development of osteomyelitis with this technique could not be dismissed.

Bone grafts were only occasionally combined with osteotomy (Fig. 86) of the phalanges. Whenever it was necessary to use a graft under these circumstances, it was removed from the proximal third of the ulna and was of the key type described by Bunnell. Results were good.

## Mobilization of Joints

Experience with mobilization of stiff metacarpophalangeal joints was good; if the condition of the hand warranted the required procedures they could be

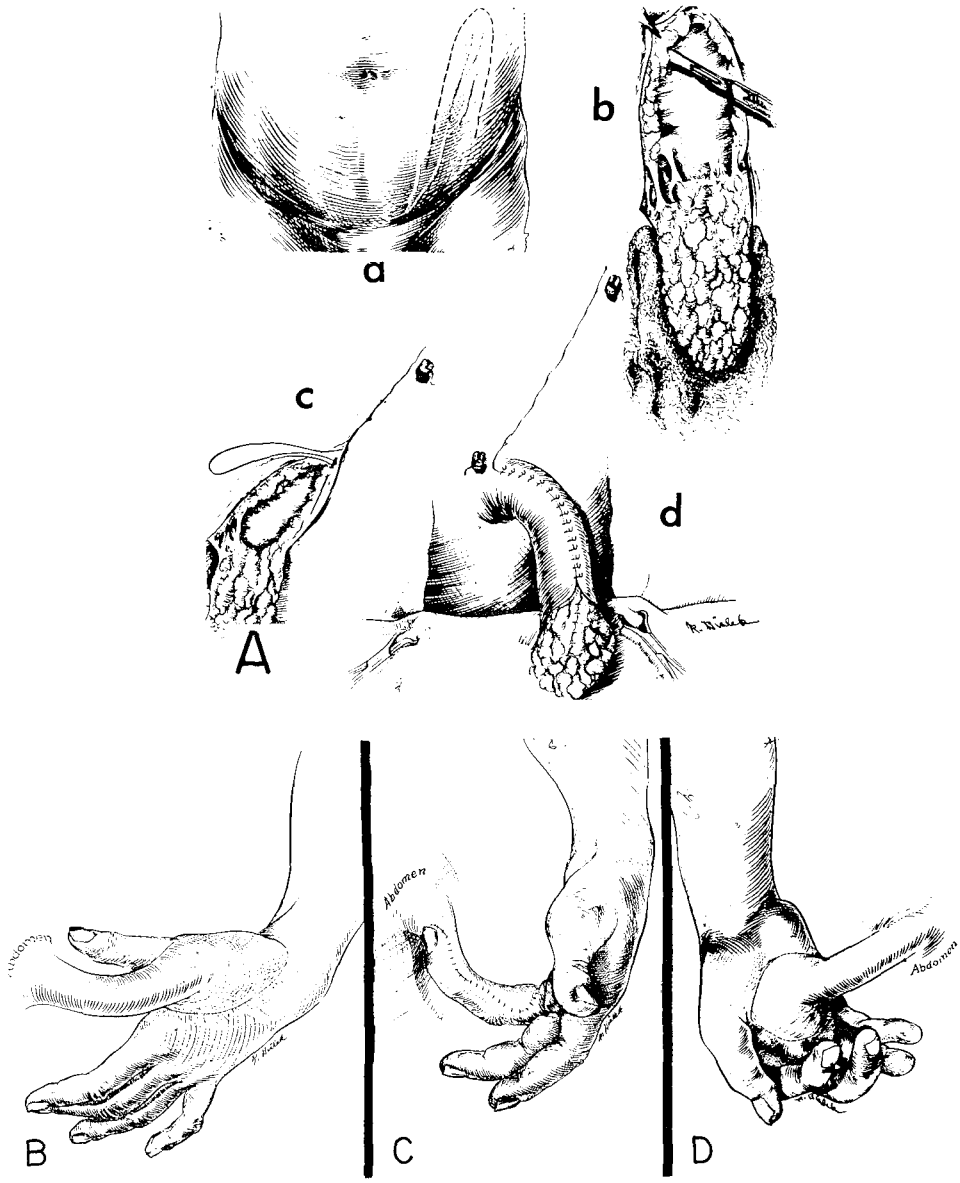



*Figure 81. Technique of construction of one-stage single pedicle abdominal flap. A a. Outline of flap on abdominal wall. b. Raising of flap, undermining of edges. c. Closure of area of flap with continuous subcuticular suture. d. Tube formed from flap. B. Application of tube to hand for contracture of web space of thumb. C. Application of tube to palmar surface of finger. D. Application of tube to palm.*

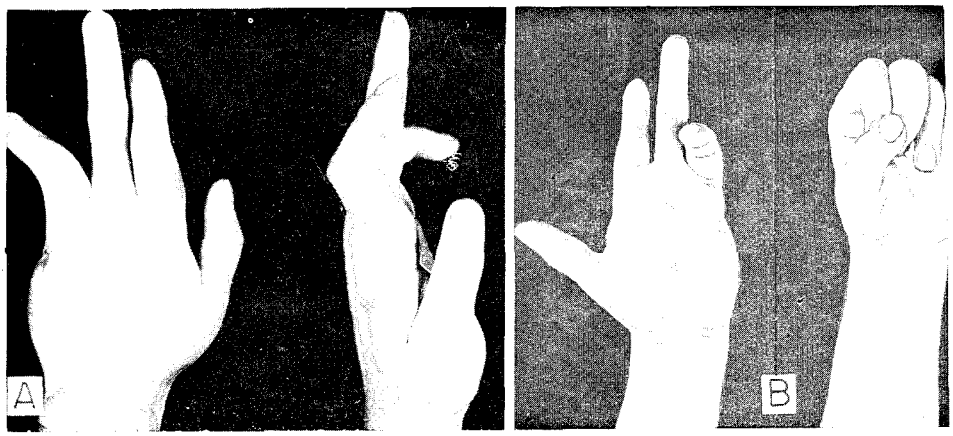



*Figure 82. Combat-incurred amputation of little finger, malunion of fractures of index and ring fingers. A. Preoperative view of hand. B. Appearance and range of motion of ring finger following osteotomy.*

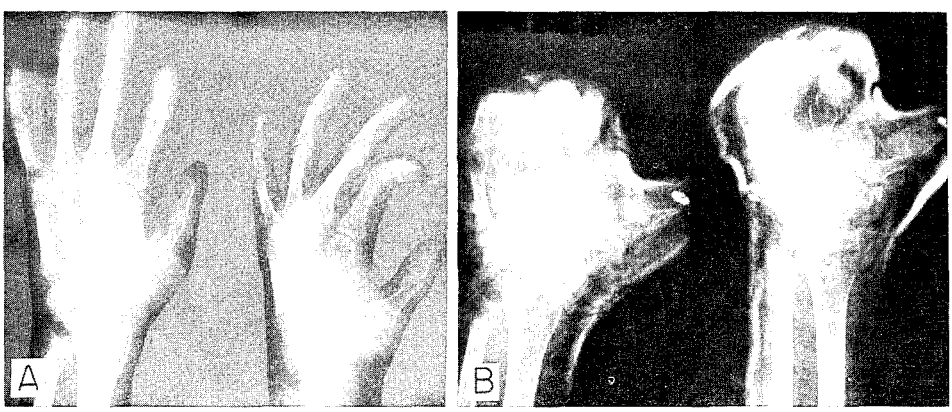



*Figure 83. Malunited fracture of second metacarpal on left hand. A. Preoperative roentgenograms. B. Postoperative roentgenograms showing pin fixation of fracture.*

mobilized and given a satisfactory range of motion with stability. Several methods of mobilization were used. Traction was the first. It was applied by the knuckle bender type of splint devised by Bunnell (Figs. 6 and 7) or by plaster of paris casts with incorporated wire outriggers and fixed irremovable traction to the digits. The latter method was most satisfactory in patients who were not entirely cooperative and in joints where stiffness seemed unyielding.

If traction succeeded, it was almost always successful within 3 weeks. If by that time it had not been effective capsulotomy was resorted to provided the cartilaginous joint surfaces were intact or relatively intact; if they were not, arthroplasty was employed (Figs. 87 and 88).

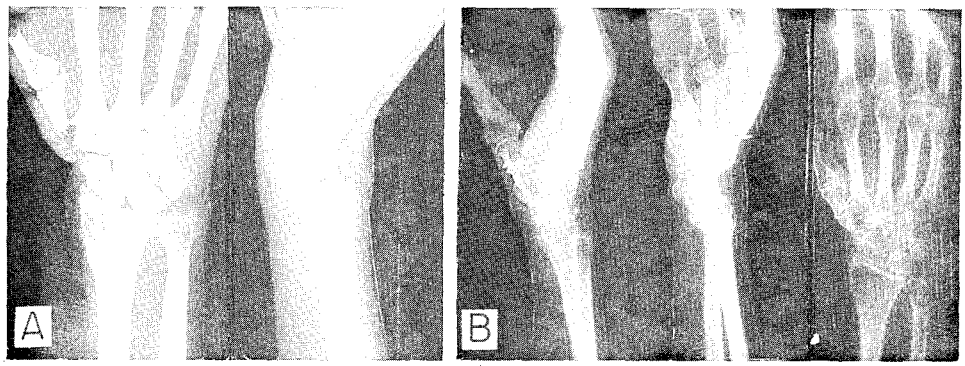



*Figure 84. Combat-incurred loss of proximal portion of metacarpal of right thumb and multangular bones. A. Preoperative roentgenograms. B. Postoperative roentgenograms showing bone graft from navicular bone to first metacarpal, with pin fixation.*



*Figure 85. Roentgenograms showing migration of proximal pin inserted to transfix second metacarpal. Migrations of this sort were fairly frequent but gave rise to no difficulties because transfixion pins were never left in situ permanently.*

Capsulotomy consisted of complete excision of the collateral ligaments. If this was not sufficient, it was necessary to strip the anterior capsule away from the head of the metacarpal. In many instances the extensor tendon was implicated in the scar and tendolysis was necessary. After correction had been accomplished by capsulotomy, the patient wore a splint for 3 weeks with the wrist dorsiflexed and the metacarpophalangeal joints flexed. The original splint then was replaced with the removable knuckle bender type of splint which was worn only part of the time. If the deformity appeared to be recurring, fixed traction was resumed. Recurrence was noted in two special

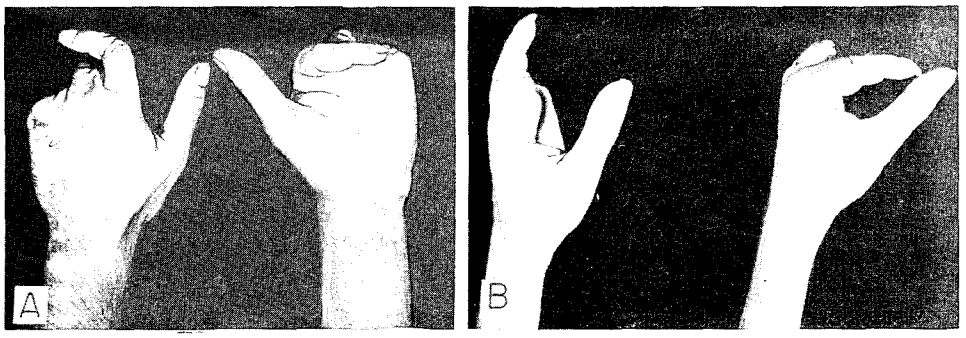



*Figure 86. A. Combat-incurred amputation of left middle, ring, and little fingers, deformity of index finger from malunited fracture of middle phalanx. B. Appearance and range of motion of finger following osteotomy and bone graft.*

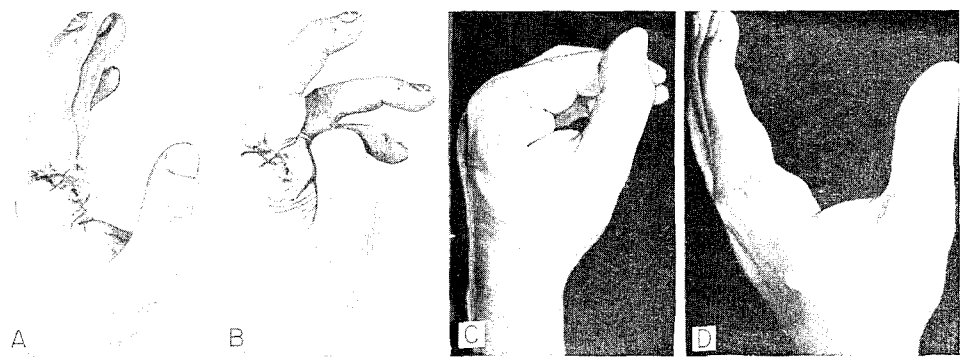



*Figure 87. Combat-incurred amputation of left index finger and ankylosis of middle finger. A and B. Preoperative status and limitation of motion. C and D. Postoperative range of motion following arthroplasty on metacarpophalangeal joint.*

groups of cases: In the first the extensor tendons were caught in the scar with restriction of their normal excursion. In the second the intrinsic muscles, which are the only direct flexors of the metacarpophalangeal joints, were paralyzed.

Cases in which the intrinsic muscles were paralyzed were managed by tendon transfer of the sublimis to the extensor apparatus. Those in which the tendons were caught in the scar were managed by tendolysis. Arthroplasty (Figs. 87 and 88) was reserved for cases in which there was destruction of the cartilaginous surfaces of the metacarpophalangeal joints; with this operation, up to 70 degrees of stable, active motion could be expected. The basic principle of operation was to secure a joint space of approximately a centimeter, with paratendinous fascia interposed between all raw surfaces.

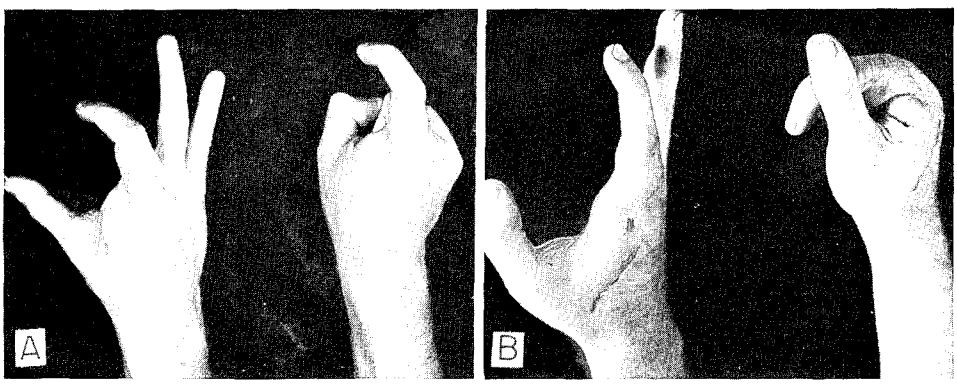



*Figure 88. Combat-incurred amputation of right index finger; ankylosis of all joints of middle finger. A. Preoperative status. Adhesions of extensor apparatus prevent active extension of interphalangeal joints. B. Range of motion following arthroplasty.*

Postoperative care in these cases involved the use of a traction splint for 3 weeks with the metacarpophalangeal joint flexed approximately 45 degrees. A removable splint, worn only at night and designed to flex the metacarpophalangeal joint, was worn for another 2 to 3 weeks.

Mobilization of stiffened interphalangeal joints was accomplished almost entirely by traction and physical therapy. Neither capsulotomy nor arthroplasty gave successful results. When, as happened in a certain number of cases, the extensor apparatus was caught in the scar over the proximal phalanx or the metacarpophalangeal joint, the extension of deformity was relieved by lysis of the extensor apparatus and interposition of paratendinous tissue.

## Peripheral Nerve Surgery

Repair of nerves about the wrist and in the hand and fingers was usually very successful. The few failures encountered could be attributed to separation of the suture line or to excessive scarring about the nerve. Sensation was observed to return at about the expected rate of an inch a month, but the finer senses such as stereognosis did not usually return for at least a year following the first return of light touch and pain sensation.

Nerve grafts were seldom employed and were unsatisfactory when used, although the number of operations was too small to be of significance.

Partial neurorrhaphy was generally satisfactory. When a nerve had been partially severed it was usually possible to separate the fibers still in continuity without major damage to them and to accomplish satisfactory anastomosis of the severed fibers. Very fine silk (No. 7–0) was used for suture material. Markers of fine tantalum wire frequently were placed distal and proximal to the suture line so that separation of the nerve ends following suture could be

checked, as necessary, by roentgenograms. Tantalum foil was not placed about the suture line in any operation done at this hospital and it had to be removed in every case in which it had already been placed because of bursa formation, interstitial cicatrization within the nerve, or fragmentation of the substance.

Return of function in the intrinsic muscles of the hand following neurorrhaphy was delayed much longer than return of sensation. It became an increasingly common practice to perform opponens transfer at the time of median nerve repair. Transfers for paralysis of the ulnar nerve were also done following neurorrhaphy if any tendency to claw deformity of the fingers was evident.

## Tendon Grafts and Transfers

When cases were properly selected, tendon grafting proved a thoroughly satisfactory procedure (Figs. 89 and 90). Results were not good when soft tissues were scarred, joints stiff, or sensation absent. When local conditions were ideal, extensor tendon grafting usually produced almost complete return of function. Flexor grafts were not quite as successful although under optimum conditions flexion and extension to within a few degrees of normal were achieved. Bunnell's technique for flexor tendon grafting with wire pullout stitches was used almost exclusively. In some cases secondary lysis of a tendon graft gave good results.

Tendon transfers (Figs. 91 and 92) gave gratifying results, especially when employed in radial nerve paralysis. At first the technique of Robert Jones* was used exclusively. By this method the pronator teres is sutured into the extensor carpi radialis longus in the upper third of the forearm, the flexor carpi radialis is transferred into the abductor and extensors of the thumb

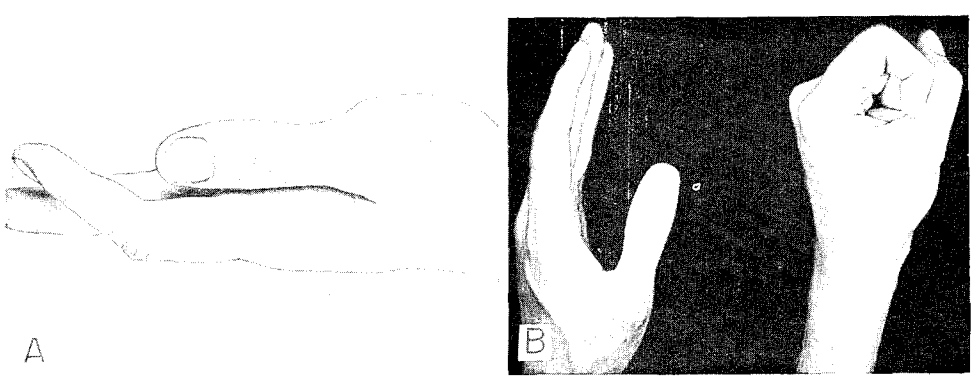



*Figure 89. Laceration of extensor apparatus of left index finger. A. Preoperative status. B. Flexion and extension following tendon grafts from middle phalanx into first lumbrical and second dorsal interosseous muscles.*

*Jones, R.: Tendon transplantation in cases of musculospiral injuries not amenable to suture. Am. J. Surg. 35: 333, Nov 1921.

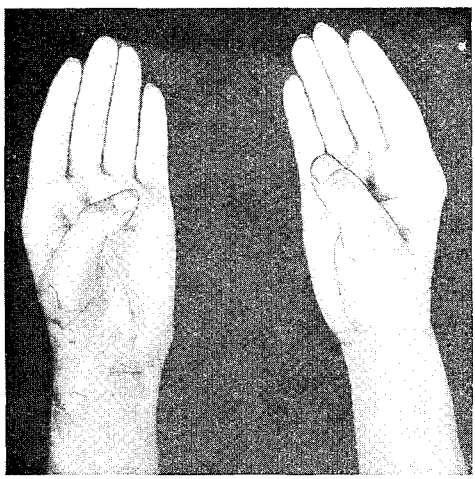


*Figure 90. Comparative range of motion of right and left thumbs subsequent to tendon transplant of left palmaris longus tendon following battle-incurred injury. The extensor pollicis brevis was detached at the point of origin and rerouted subcutaneously across the palm toward the pisiform bone where it was anastomosed to the palmaris longus.*

at the level of the wrist, and the flexor carpi ulnaris is transferred into the extensor digitorum communis at the same level. There were two objections to this technique: (1) Since the abductor and the long extensor of the thumb have different excursions, when the same muscle was inserted into both tendons it could not act fully on the tendon with the longer amplitude of excursion. When the flexor carpi radialis was sutured into both the abductor and the extensor pollicis longus, it could not act to extend completely the distal segment of

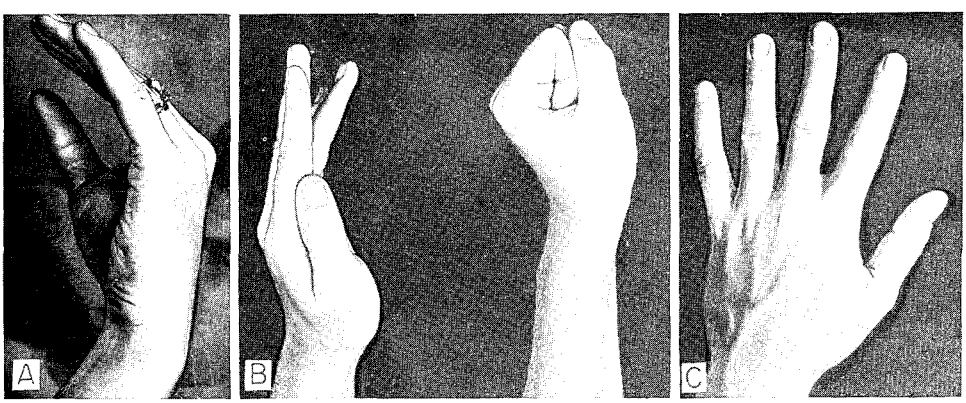



*Figure 91. Irreparable paralysis of left radial nerve following combat-incurred injury. A. Preoperative inability to extend wrist and digits. B. and C. Postoperative range of motion following tendon transplant.*

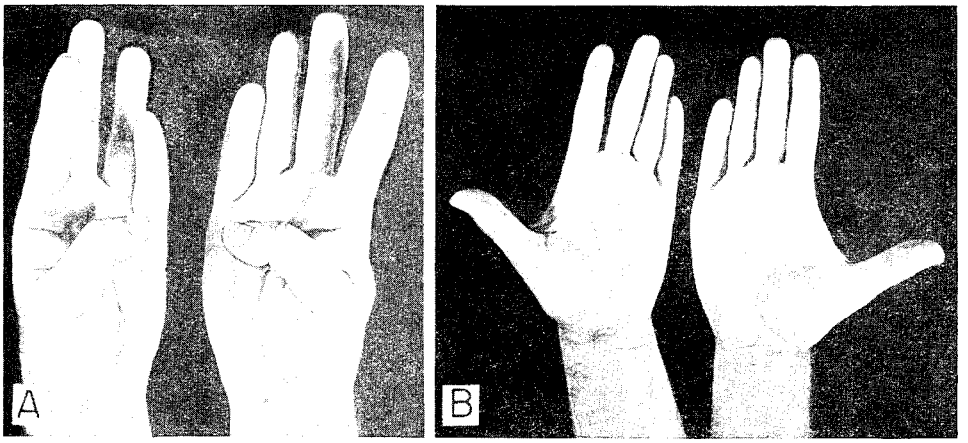



*Figure 92. Paralysis of left extensor pollicis longus and extensor indicis proprius muscles following penetrating shell fragment wound. A and B. Comparative range of motion of right and left thumbs following tendon transplant of left flexor carpi radialis into extensor pollicis longus and extensor indicis proprius.*

the thumb. (2) Sutures placed on the dorsum of the wrist were very prone to become adherent, with the result that when the patient attempted to extend his fingers, most of the effort had to go into pulling the wrist back.

The Jones procedure was modified so that the transfers were done proximal to the dorsal carpal retinaculum. If the palmaris longus was present, it was sutured into the abductor pollicis, the flexor carpi radialis was sutured into the extensor pollicis longus and the flexor carpi ulnaris into the extensor digitorum communis above the dorsal retinaculum. The pronator teres was sutured into the extensor carpi radialis, as in the Jones procedure, to give the wrist dorsiflexion.

The results of the modified operation were very satisfactory. There was a minimum of adhesions at the suture line. Some patients had complete use of the transfer as soon as the cast was removed (4 weeks after operation), though others required several months to isolate the action of a particular muscle.

When tendon transfers were done every effort was made to secure a muscle as nearly as possible of the same amplitude of excursion as its predecessor. The amount of power necessary to accomplish the desired functions was also taken into account. A wrist extensor, for instance, would be transplanted into the long extensor of a digit only as a last resort, when nothing else was available.

## Amputations

No thumb and no other digit was amputated until it was clear that there was no possibility of salvage (Fig. 93). When it was impossible to avoid am-

putation, as much length as the nature of the lesion permitted was preserved, and every effort made to save some portion of the digit in order to keep the normal span of the hand and the strength of the grasp. The fishmouth type of incision was used whenever it was feasible, with the palmar flap the longer, though this was not always possible. Digital nerves were isolated, pulled out and ligated. In the experience at Baker General Hospital it was found necessary to ligate only the volar digital nerves. If the entire length of the finger had to be sacrificed, it was preferred to leave the metacarpal intact except for shaving off the head, to prevent the possible formation of a bursa between the metacarpal head and the skin; otherwise, a painful stump would result. When the metacarpal was amputated proximal to the head, the fingers showed a tendency to scissor. This was not observed when the metacarpal head was left in situ.

In some instances in which the hand was narrowed by scarring of skin and soft tissue, the entire metacarpal was excised and the adjacent ray shifted into

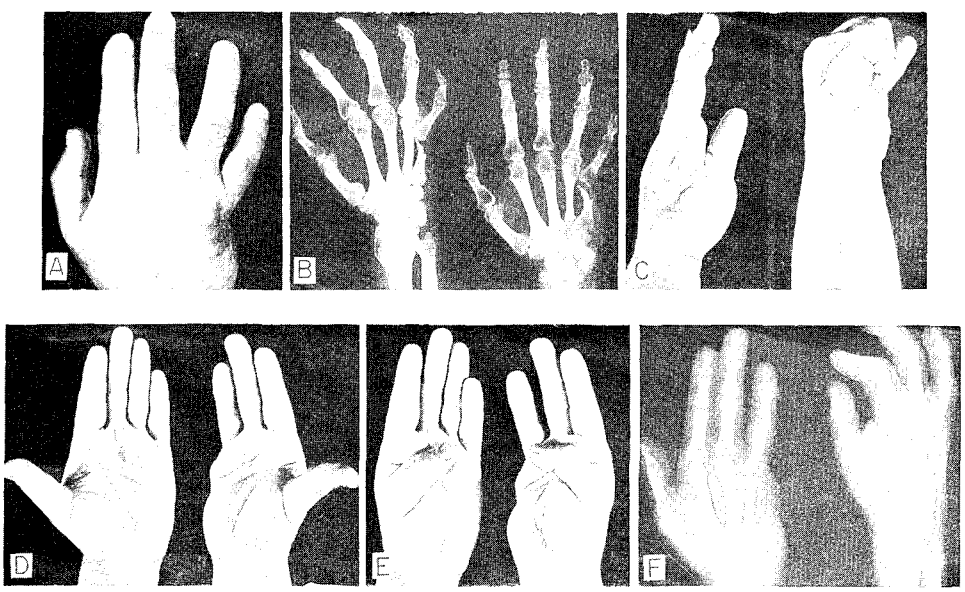



*Figure 93. Ankylosis of fourth metacarpophalangeal joint, cicatrix on ulnar aspect of right hand following battle-incurred injury. The little finger is motionless and anesthetic and the extensors of the thumb and index finger are paralyzed. A. Preoperative dorsal view of hand. B. Preoperative roentgenograms. C. Possible flexion and extension of ring finger following amputation of useless little finger and arthroplasty. Flap from little finger has been utilized to replace ulnar cicatrix. D and E. Extension and flexion of thumb following tendon transplant. The long extensors to the little finger were used as motors. F. Postoperative roentgenograms.*

its place. In this procedure it was necessary to remember that the extensors of the wrist insert into the second, third, and fifth metacarpals, so that the bases of these bones should be left. The shift was carried out by osteotomy distal to the insertion of the extensors of the wrist.

## Reconstruction and Transplantation of Digits

In several instances total reconstruction of the thumb was attempted but results were always discouraging. Skin tubes did not heal well and it might be many months from the construction of the tube until the final application and healing of the bone graft. Sensation developed slowly in the reconstructed thumb and epicritic sense was never normal. The experience of one patient subjected to this operation was typical: Immediately after reconstruction was completed he was thoroughly satisfied with the results; at the end of 3 months he knew that the procedure had not proved worthwhile. That was also the opinion of the hand surgeons on the staff.

Transplantation of a finger or toe to take the place of a missing thumb was never attempted.

## Prosthesis

In a few instances the Dental Department at Baker General Hospital constructed prostheses for patients who had lost thumbs. Cosmetically these prostheses were quite satisfactory and the patients liked them, but they had no functional value and their effect was entirely psychologic.

## Rehabilitation

Occupational therapy proved of considerable value and physical therapy of little worth in the rehabilitation of crippled hands either before or after operation. Occupational therapy made patients use their hands for various purposes and for long periods of time; physical therapy accomplished no such results.

The most notable functional recoveries occurred while patients were on furlough, particularly if they engaged in milking, ploughing, and other work about a farm. Men who showed the greatest benefits were those who honestly tried to use their hands constantly. If they did not cooperate, no results were achieved.

The hand surgeons at Baker General Hospital were rather generally opposed to passive exercises. After operation each patient was carefully instructed in active exercises by the ward medical officers. Patients who had been submitted to tendon transplants received full explanations concerning the muscles affected by the operation. It consumed considerable time for medical officers to instruct the patients, but it was necessary if the proper results were to be achieved.

CHAPTER VII

# Hand Surgery at William Beaumont General Hospital

*William H. Frackelton, M. D.**

## Administration

By the fall of 1944 patients with hand injuries were being admitted in such numbers that their management by consultation between the plastic, general surgical, and orthopedic sections proved cumbersome and inadequate. A hand clinic was therefore set up with a staff composed of an orthopedic surgeon and a member of the plastic service who had had special neurosurgical and orthopedic training, also specific training in hand surgery under Dr. Sumner Koch. Conferences were held at regular intervals and were attended, as far as possible, by members of the general surgical, orthopedic, and plastic surgery sections.

At these conferences were seen patients with all types of injuries of the upper extremity involving damage to skin, subjacent tissues, nerves, bones, joints, or tendons. Their conditions were discussed and a repair program outlined for each man. Thus, the patient with a hand injury had the benefit of a carefully planned program before any step of reconstruction was initiated.

The desirability of treating all patients with hand injuries as a segregated group was fully realized, but the large number of injuries and the limited personnel available for their care made this plan impossible. Patients segregated were limited to those with injuries of nerves or tendons and those with some combination of bone, joint, nerve, tendon, or skin damage. With few exceptions injuries requiring only repair of skin and subjacent tissues were cared for on the plastic section, while those needing only repair of bones and joints were treated on the orthopedic section.

Segregation permitted the proper supervision of corrective splinting and the institution of physical and occupational therapy both before and after operation. It was also possible to schedule patients for operation as rapidly as facilities and personnel permitted, and to perform as much surgery as was feasible at a single operation.

Patients with hand injuries who were in other parts of the hospital because of additional body injuries were similarly supervised by surgeons assigned to the hand clinic.

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*Assistant Professor of Clinical Surgery, Marquette University. Formerly Colonel, MC, AUS.

## Personnel and Training

The Beaumont General Hospital Hand Center was no more fortunate than other hand centers in obtaining surgeons who met the necessary requirements. A training program was therefore set up. Of the 11 officers assigned to the hand group during the period of its existence, 1 only had received in civilian life, in addition to special training in orthopedic and plastic surgery, some training in hand surgery. Four others had undergone special training in plastic or orthopedic surgery, while 1 had been trained both in orthopedic and neurosurgery.

The instruction program included theory and practice. One and one-half hours weekly were spent on anatomic and technical problems. Reports from the literature were correlated with appropriate cases under treatment. Senior staff members led the discussions and made full explanations, but free and spontaneous give and take between all participants was encouraged.

Reading lists were provided and reports on this material were made part of the training program.

Guidance of the Civilian Consultant in Hand Surgery, Dr. Sterling Bunnell, was most helpful in developing the training program. Similarly the three visits to the hospital in 1945 by the orthopedic consultant for the Eighth Service Command were fully utilized. He made clinical suggestions and aided in the disposition of the special administrative problems peculiar to hand patients.

One phase of the hand training program which proved valuable in the clinical management of patients was the division of the members of the hand group into teams. Inexperienced members were assigned to work with men experienced in one specialty or another, so that the whole group was properly balanced.

Each individual, in addition to general duties, had specific responsibility for devising the plan of treatment for each patient allotted him. After the plan had been worked out it was discussed with the team, and with the chief of the group, before final acceptance.

## Reconstruction Problems

Injuries treated consisted for the most part of those sustained in combat, or were combat-connected. Well over half of them were enemy-inflicted wounds; accidents sustained in vehicles, by machines, from powder explosions, and from burns, accounted for something over a quarter. The remainder comprised injuries from self-inflicted wounds, as by the accidental discharge of a rifle, and such nontraumatic conditions as infections, Dupuytren's contracture, and similar lesions.

For the first 10 months of 1945, 1,398 patients were treated on the hand service of Beaumont General Hospital, 772 by major, and 43 by minor operations. There were 1,030 consultations with other hospital sections. An analysis of 298 consecutive, completed surgical cases of combat or combat-connected origin (Table 12) showed that skin grafting or shifting of tissues was most frequently required. Next in order of frequency came operations on bones, nerves, tendons, and joints. A mere naming of the operations performed does not indicate the burden of work in this or any other hand center. The 298 patients in this particular group were submitted to 361 separate operations, in

TABLE 12. DISTRIBUTION OF PROCEDURES IN 361 SEPARATE OPERATIONS [1] ON 298 PATIENTS WITH HAND INJURIES AT BEAUMONT GENERAL HOSPITAL IN 1945 [2]

| Type | Number | Total |
|---|---|---|
| Skin | | 249 |
| Free graft | 53 | |
| Pedicle | 47 | |
| Other procedures | 149 | |
| Bones | | 151 |
| Graft | 27 | |
| Reduction with fixation | 6 | |
| Removal of wires | 7 | |
| Osteotomy | 54 | |
| Other procedures | 57 | |
| Nerves | | 148 |
| Graft | 8 | |
| Neurorrhaphy | 26 | |
| Neurolysis | 26 | |
| Neurotomy | 80 | |
| Other procedures | 8 | |
| Tendons | | 133 |
| Graft | 21 | |
| Tenorrhaphy | 17 | |
| Transfer | 32 | |
| Tenotomy | 19 | |
| Tendolysis | 35 | |
| Other procedures | 9 | |
| Joints | | 54 |
| Capsulectomy | 19 | |
| Arthroplasty | 12 | |
| Arthrodesis | 13 | |
| Other procedures | 10 | |
| Miscellaneous procedures | | 88 |
| Total procedures | | 823 |

[1] No accounting is made of the multiple similar procedures performed in the course of a single operation, nor is removal of wires in ward dressing rooms included.

[2] Tabulation represents only the operations completed in the course of a single year.

which 823 distinctive procedures were carried out. Each patient with a hand injury averaged about 3 procedures at every operation. Even these figures do not accurately reflect the volume of surgery since they indicate only the type of operation undertaken, whereas often several tendon grafts or more than one bone graft would be performed in the course of the procedure.

## PREOPERATIVE ROUTINE IN RECONSTRUCTIVE SURGERY

Adequate examination of an injured hand included the following: (1) A determination of extent of the injury; (2) a decision whether medical or surgical treatment was required; (3) if surgical, the necessary operative procedures and their sequence; (4) an analysis of anticipated functional results; (5) an evaluation of psychologic and economic factors in the case. Economic factors, in the usual sense of the term, could be disregarded in military service, but the type of work which the patient had done or intended to pursue in the future sometimes influenced the decision concerning surgical procedures, particularly if amputation was a consideration.

In addition to the written record of examination, a large diagram of the hand was employed. On this were noted the observed defects tabulated under the tissues involved, procedures advised, and sequence and combination of these procedures—the objective being to reduce the total number of operations required.

Before operation, time was allowed for healing of wounds, corrective splinting, occupational and physical therapy. The last named was employed to improve circulation, reduce edema, and soften cicatricial tissues. It provided passive motion of the parts before the patient could initiate active motion, stimulated muscle tone, and indirectly enhanced nerve regeneration. Occupational therapy provided tension to overcome contractures of ligaments and tendons, intermittent muscle contractions to give increased power, and adaptation movements for useful work. It allowed the patient to be his own judge of pain and put upon him the responsibility of avoiding edema, stiffening, and other residual damage.

## INJURIES SUSTAINED IN TRAINING

Not many burns of the hand were received as fresh injuries; those treated in early stages were chiefly the result of gasoline explosions. The Southwest was a center for many thousands of troops in training and burn injuries were not infrequent, but they were usually treated at appropriate station hospitals.

Standard treatment consisted of cleansing of the wound under sterile precautions and application of voluminous pressure dressings. The hand and arm were placed on a metal splint in the position of function; dressings of the

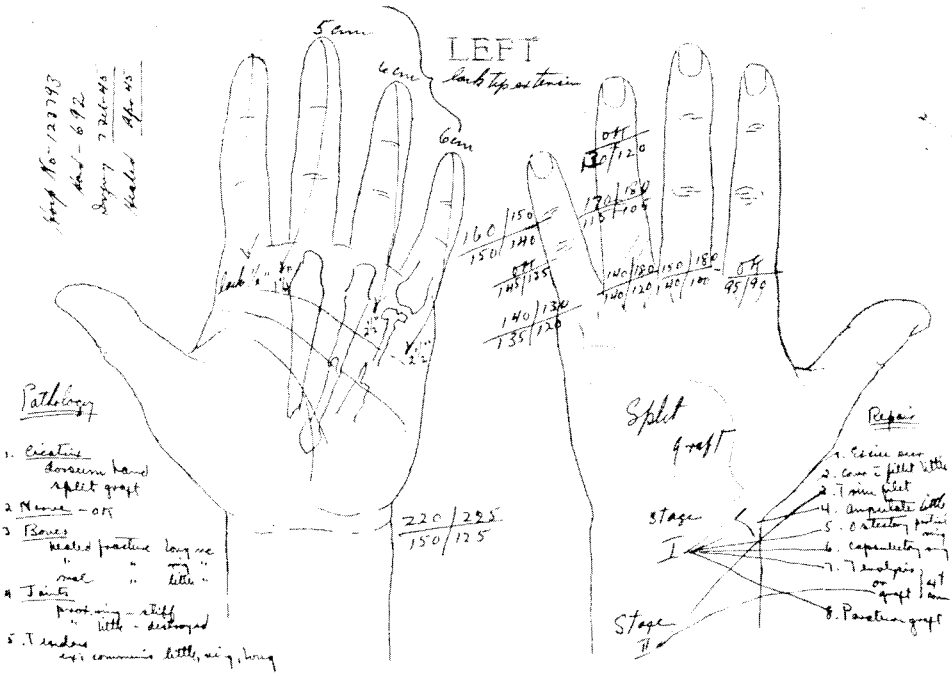



*Figure 94. Working diagram (Beaumont General Hospital Hand Center) for repair of left hand following injury to dorsum with destruction of head of fifth metacarpal, adherence of extensor tendons of long and ring fingers and stiffening of proximal joint of ring finger in extension. A split thickness graft had previously been applied to the dorsum. The two-stage reconstruction included: excision of split thickness graft on dorsum; excision of fifth ray, with preservation of nerves, blood supply and skin flap; ostectomy, at an oblique angle, of base of fifth ray; excision of cicatrix in and about the dorsum; lysis of extensor tendons; ostectomy of protuberant bone at site of a fairly well-healed fracture of metacarpal of ring finger; capsulectomy of proximal joint of ring finger, and removal of collateral ligaments. A large paratenon graft (obtained from the thigh) was placed underneath extensor tendons of ring and long fingers. Flexor tendons to little finger were drawn up and cut off short in palm. Closure was achieved with subcutaneous and cuticular wire sutures after wide mobilization of skin edges and utilization of skin and subcutaneous tissue of the fifth ray in the form of a dorsal flap. For fear of damaging the blood supply dog ears of flap were not removed until a subsequent operation. Hand was splinted in plaster in cock-up position. Light flexion traction was applied to ring finger. Occupational and physical therapy were used intensively preoperatively and postoperatively. Three-and-a-half months after operation digital flexibility was excellent. An extensor tendon graft, which had originally been contemplated, was not required.*

fingers were individualized according to necessity, and changed only at long intervals. Under this mode of treatment early skin grafting was usually possible.

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Prior to adoption of this mode of treatment in February 1942, treatment of burns consisted of various topical applications.

Both simple and compound fractures involving bones of the hand and wrist were treated by the usual measures. Until 1944 a sulfonamide drug was used locally in all compound fractures. This practice was then discontinued (see Chapter I, p. 8) with no apparent worsening of results. Use of the banjo splint (Fig. 2) for fractures of phalanges or metacarpals was discouraged. Internal fixation of fractures was chiefly limited to cases on which both bones of the forearm were involved and in which other methods of retention were not feasible.

Traumatic amputations were treated by split or free full thickness skin grafts, especially when terminal phalanges were involved.

Crushing injuries were treated first by cleansing the wound under sterile precautions, applying voluminous pressure dressings, and splinting. As soon as possible thereafter (usually within 10 to 14 days) necrotic skin and subjacent tissue were removed and skin grafting done.

## INFECTIONS

Morbidity and permanent disability among patients with hand infections were greatly reduced when the policies introduced by the surgical consultant for the Eighth Service Command were adopted in 1943. Incision and drainage for so-called minor hand infections were no longer carried out in dispensaries of troop organizations in the command. All patients were referred to hospital outpatient clinics, where decision was made as to whether the patient could be treated on an ambulatory basis or required hospitalization. All patients but those with the most trivial infections—chiefly small epithelial abscesses and furuncles—were hospitalized (see Chapter I, pp. 8–10).

Treatment consisted of (1) splinting in the position of function, (2) application of warm moist compresses, and (3) administration of sulfonamides and later, when it had become available, of penicillin. When required, surgical incision was carried out under general anesthesia, in anatomic planes, in a bloodless field provided by use of a tourniquet. Under this form of treatment permanent disability was avoided and the number of days lost from duty was greatly reduced.

## SPECIAL TYPES OF INJURY

### Burns

Some patients received from overseas with deformities resulting from burns had had a portion of the necessary reconstructive surgery performed in hospitals to which they had previously been admitted. Surgery in cases in which reconstructive operations on tendons, joints, or nerves were not necessary was confined to replacement of cicatricial contractures with heavy split grafts.

Many patients were received with large dorsal cicatrices which, although healed, were unstable. Joints and tendons not directly injured by burns were frequently damaged by constriction and immobility because of superimposed cicatrices. Joint stiffness was likely to be even more pronounced than instability of the cicatrix.

*Preoperative Measures.* In all such cases the patient gained by at least 2 weeks of intensive supervised occupational therapy and corrective splinting. Ligaments were stretched, suppleness of the deep tissues was partially restored, and the hand came more nearly into a position of function when the cicatrix was removed at operation. A soft leather glove fitted with elastic straps from fingertips to wrist formed a good corrective splint. Occupational therapy consisted chiefly of work with soft materials requiring flexion of fingers and opposition of the thumb. Loom weaving and woodworking were particularly suitable for this purpose. Direct trauma was avoided, since the measures described could be carried out without splitting and fissuring the scar.

*Points of Technique.* Important points of technique included the following: Thicker grafts always gave better function than thinner ones, which made the back a particularly suitable donor site. From it a graft 0.025 inch thick could be obtained without damage to the donor site. Use of a sphygmomanometer as a tourniquet afforded a bloodless field, permitting dissection and cleavage of the cicatrix and uninvolved tissue. Special care was taken to remove the whitish layer of scar. Longitudinal lines were avoided when the cicatrix was excised over the fingers, since straight-line suture scars cause contracture in extension at a graft margin. Transverse lines at the crest of the thenar web were also avoided (Figs. 95 and 96). Reasonably large areas of normal skin near the wrist could be swung pedicle fashion to form transverse lines with the graft. Portions of normal skin were removed to create a wave-like line on the dorsum of the ulnar aspect of the hand and on the fingers. Excision was carried over to the midlateral line on the fingers and the convexity of the wave line was placed at the joint of the finger (Fig. 96 b and e).

Size of the graft was extremely important (Fig. 96 e). The extended hand has a smaller dorsal surface area than a clenched hand (by actual measurement the difference is 30 to 40 percent). This is explained by the elasticity of the dorsal skin, presence of loose subcutaneous tissue, of plications and wrinkles which can unfold, and absence of restraining lines of tension along extensor surfaces of the finger and the thenar web. These properties are lacking in a burned hand, and the principle of restoration is to supply an elastic, vascularized skin covering of sufficient surface area, devoid of restraining suture scar lines.

Ideally a graft is applied at normal skin tension, but even under these circumstances a shrinkage of 10 to 20 percent can be expected. In burned hands the temptation to stretch a single sheet of grafted skin over a raw dorsal surface of any size was deliberately avoided; two sheets were always preferable.

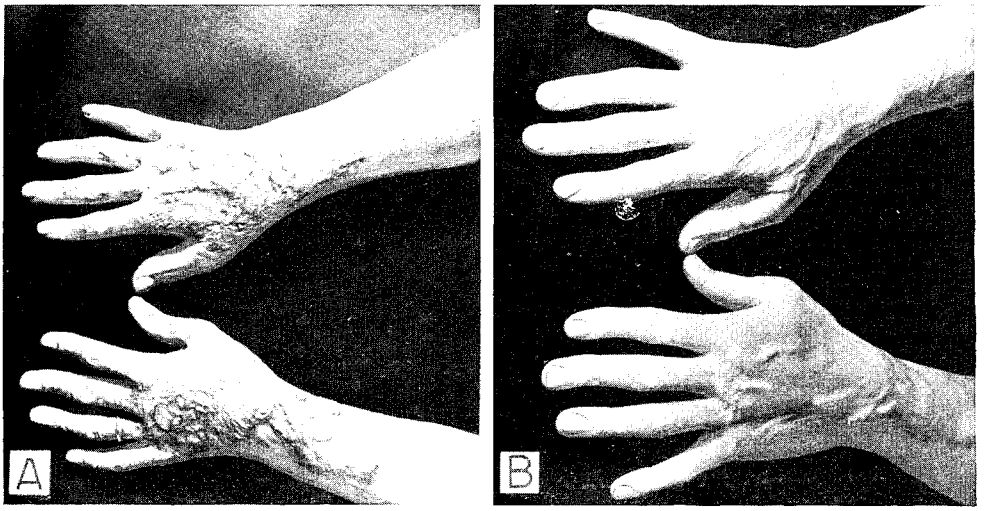



*Figure 95. Cicatricial deformity and contractures of both hands secondary to burns incurred in airplane crash. A. Preoperative view. B. Condition of hands following excision of cicatrix, Z-plasty, and heavy split skin graft of hands and wrists. This patient could be returned to pilot status.*

The proximal sheet was placed transversely in the axis of length of the graft. The second sheet was best applied after it had been cut to pattern (Fig. 96 e). Breadth from the ulnar border of the hand to the radial border of the opposed thumb is often as much as 6 inches. With the hand in this position, and with the fingers flexed, a pattern was outlined by means of sterile transparent X-ray film and methylene blue, and the graft was cut from this pattern after it had been trimmed. When this plan was used, the graft was fitted into the wave line of excision by measurement, and normal skin tension was thus obtained.

After skin grafting webs often formed at the interdigital spaces and correction required a second operation. To avoid such webs one of two methods was used. The first, devised by Schuessler,[1] was suitable when the cicatrix was not too thick. It required leaving in situ a spear-shaped portion of the cicatrix, with the tip of the spear pointed toward the wrist, at the base of the finger and the area immediately proximal. The other method, devised by Farmer and Woolhouse,[2] required the excision of all scar near the base of the finger (Fig. 96 c, d, and e). The potential **U**-shaped skin graft junction was then broken by Z-plasty of both the graft and the interdigital skin, the resulting zigzag line effectively preventing contracture.

[1] Lt. Col. Willard W. Schuessler, Chief, Plastic Surgery, William Beaumont General Hospital, 31 March 44 to 30 June 46.

[2] Farmer, A. W., and Woolhouse, F. M.: Resurfacing of dorsum of hand following burns. Ann. Surg. 122: 39–47, Jul 1945.

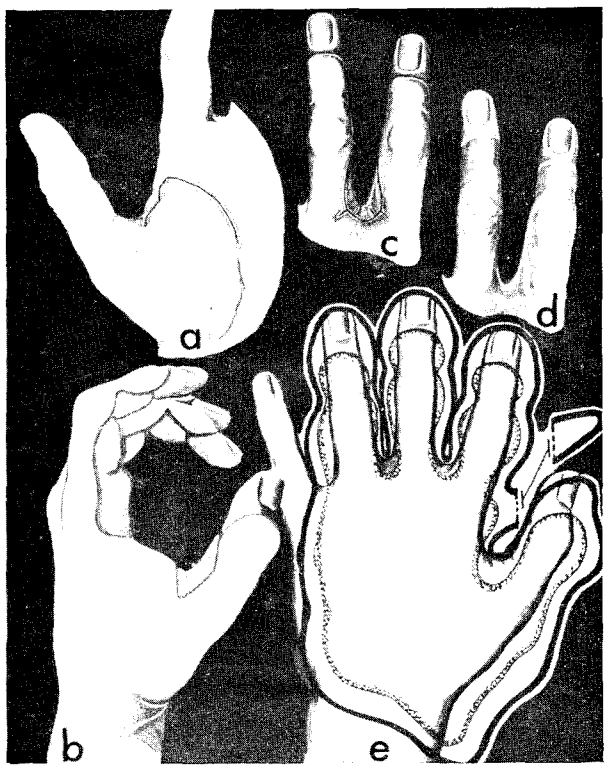



*Figure 96. Details of technical procedures carried out in case illustrated in Figure 95. a. Line of incision along thenar crease. The pedicle is swung dorsally, creating depth for the cleft and width for the crease. b. Transposed flap of palmar skin along ulnar dorsal aspect of thumb. Graft is extended over the crest of the web, so that a contracting line is avoided along this ridge on the fingers. Note wavy midlateral lines, with convexities at the joints, and Z-plasty at wrist for conversion of a longitudinal line of stress into a transverse line. c. Incisions in skin graft and in interdigital skin for performance of Z-plasty within web. d. Result after transposition of flaps and healing of small flaps. e. Area of excised cicatrix (dotted line) and of pattern of replacement (heavy black line). Note that graft is considerably larger than scarred area, to allow for coverage of hand when fist is made.*

When the dorsal thenar skin was implicated in the burn, disabling adduction of the thumb required correction. For a good result it was necessary that the thenar web be unbroken either by scar or suture line. This could be accomplished by transposition of a palmer flap to deepen the web cleft of the thumb, a wide projection of the graft being carried over the thenar ridge to provide a crest free from transverse suture. This measure gave an even greater thumb spread than the radial volar flap from the index finger space recommended by Pierce, Klabunde, and Emerson.[3]

[3] Pierce, G. W.; Klabunde, E. H., and Emerson, D.: Repair of burned hand. Surgery 15: 153–172, Jan 1944.

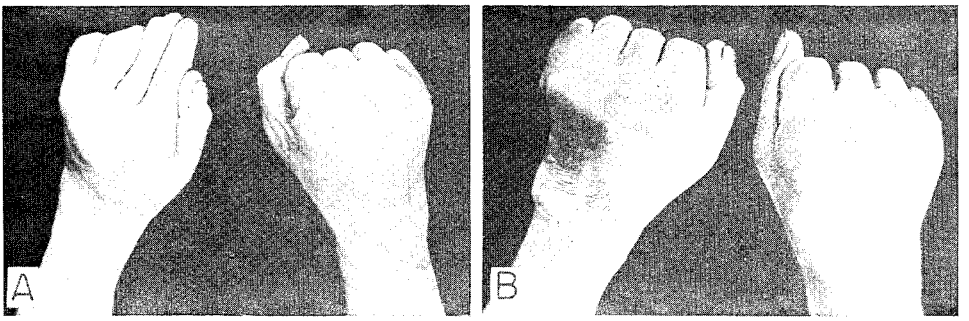



*Figure 97. Extrinsic hyperextension deformities of middle joints of index and middle fingers as result of contracture of extensor tendon apparatus following burns. A. Preoperative view. Heavy split thickness graft had been applied to dorsum of hand and fingers overseas. B. Condition of hand following lengthening of tendons under split thickness skin grafts. Complete flexion of fingers is now possible.*

Burns which had healed with cicatricial deformity and direct injury to tendons and joints, or with secondary involvement as the result of malposition, required repair by the application of pedicle skin, with joint and tendon reconstruction at a later stage. Pedicle skin was usually necessary to provide sufficient circulation in the outer covering to permit later replacement of moving parts (tendons, joints). Occasionally, however, extensor tendon repair could be carried out under a split thickness skin graft (Fig. 97).

*Postoperative Care.* A pressure dressing, with certain modifications of the usual dressing was applied postoperatively. An ordinary volar cock-up splint with a palmar plate was used, the plate being small to permit the thumb to be brought into opposition. The dorsi-extension curve usually desirable in hand injuries was reversed to allow moderate flexion of the wrist during the postoperative period. Before the splint was applied, thin wires were placed through the tips of all the fingernails. The hand was placed in flexion over a soft, rolled pad applied transversely in the palm in such a way that the fingers could flex fully in all joints. A portion of an abdominal pad about 2 inches in diameter was satisfactory for this purpose. The fingers, separated from each other by small dressing pads, were held in the position of flexion by tying the wires from the nails to a single rubber band which was attached to the forearm portion of the splint. The wire from the thumbnail was connected to a rubber band which was fastened to the outside of the dressing with the thumb in opposition. Maintenance of flexion did not depend on the tension of the wires but on the superimposed occlusive dressing. Distortion of the nails did not result from this type of dressing and the patient was comfortable during the postoperative period.

To regain joint motion occupational therapy was reinstituted about 2½ weeks after operation.

## Wounds of the Soft Parts

*Healed Wounds.* Even when wounds were fully healed, a certain period had to elapse before reconstructive surgery could be undertaken. The delay was partly to avoid the danger of lighting up an old infection and partly to allow sufficient time for maturation of scar tissue. During the period of waiting, which was occupied with splinting, physical and occupational therapy, preparation of pedicles at a distance was carried out, as was local replacement of skin and of immediate subjacent tissue.

When reconstruction involved other tissues, specific periods were allowed to elapse before reconstructive surgery was undertaken, thus:

1. Three weeks in soft tissue wounds which had healed without infection.
2. Three months in injuries with moderate infection.
3. Six months after the control of bone infections. (Occasionally, in selected cases the lapse of time was reduced to 4 months.)

These time intervals were shorter than had previously been considered necessary, the reduction, as in the case of bone infection, being possible because of the protection afforded by penicillin.

Because contracted scar in a healed wound was found to be extremely deceptive, proper preparation was necessary to provide covering tissue both when the healed wound was first operated on and at subsequent operations. Unless there had been accurate estimation of the tissue lost both on the surface and in the depths of the wound, the surgeon was likely to be confronted with a large gaping wound which resisted operative closure after removal of the small innocent-appearing scar of a healed wound.

*Infected Wounds.* In general, treatment of open infected wounds was by (1) application of hot moist dressings and later by hand and arm soaks, (2) elevation of the affected limb on pillows while the patient was in bed, and in a sling when he was ambulatory, (3) pressure dressings, and (4) removal of dead tissue at the time of dressing or operation. The hand was maintained in the position of function by appropriate splints, and joints were mobilized at least once daily when the wound was dressed or the hand soaked.

If the open infected wound was accompanied by sufficient additional damage to make reconstruction impractical, amputation of a finger (but not of the thumb) was undertaken as soon as possible, since this measure controlled infection and prevented further stiffening of the hand by binding cicatrices.

Penicillin was used routinely by the systemic route when susceptible organisms were present.

## SPLINTING

Protective splinting was used to provide rest for damaged tissues, aid healing, protect recently sutured nerves and tendons until healing had so progressed that mobilization would not tear apart sutured tissues, and protect paralyzed muscles until return of nerve sensation.

Aluminum, piano wire, and wooden or metal hand and finger pieces satisfied the requirements of lightness, ease of construction, and readiness of application and removal. In the operating room plaster slabs were commonly used, though occasionally aluminum splints, previously fashioned, were substituted. All splints were applied with due precautions against impeding circulation.

One member of the hand group who had been a prisoner of war described a splint he had employed for metacarpal fractures when he was without adequate supplies to treat his patients. It consisted of a flat board, with a mounted triangular block of sufficient size and proper shape at the distal end to force the metacarpal fracture into alinement and elongation when the proximal joints of the finger were bent over it. This splint was found to give better results than the bandage roll frequently used for the purpose.

For corrective splinting continuous gentle elastic tension gave gratifying results. To overcome stiffness, the cock-up splint was most often used (Fig. 3). It provided elastic dorsal wrist correction. For traction at right angles to the stiffened joints leather loops over the digits could be added with attached rubber bands which were carried over an adjustable U-shaped bar of piano wire fixed to the forearm piece. Opposition of the thumb was obtained by hooking on the ulnar side of the forearm piece a piano wire outrigger connected with a rubber band and leather loop about the thumb.

Spring steel (corset steel) strips were used to overcome flexion deformities of the fingers. These were held to the dorsum of the fingers and hand by narrow, light, leather straps and were removable. Short sponge-rubber cylinders in graduated sizes proved effective in overcoming adduction contractures of the thenar web.

Inelastic wedging splints were seldom used. When they were indicated, extreme caution and gentleness were mandatory.

Though tension was decreased at night patients were advised to wear their splints at night as well as during the day. They could be removed for necessary personal care, for occupational and physical therapy, and for 10-minute periods every 2 hours during the day, so that fingers and hand could be exercised.

## SKIN GRAFTS AND REPLACEMENTS

The simplest type of graft or other replacement which would satisfy functional requirements was ordinarily indicated. Split grafts were used to cover open wounds and expedite healing; thick split grafts were employed when the injury did not involve or markedly impair structures beneath the normal skin and subjacent tissues; full thickness grafts were applied for the palm and volar surfaces of the fingers if very heavy split grafts did not suffice; pedicles were used with skin and subjacent fat for defects with underlying damage. Direct pedicle flaps were most often prepared because they

saved time and reduced the number of operative steps necessary, while tube pedicles were applied to areas in which direct flaps were not suited, such as defects in the middle of the palm. Tube pedicles were also used for aseptic closure, especially on fingers in which tendon grafts were to be placed later.

Whenever possible a direct flap was used, with elevation and application carried out in a single stage; very large areas could be covered in this manner. The base pedicle of the flap was always made extremely wide (Fig. 98 B), as wide as, or wider than, the defect; sufficient blood supply was thus provided. There was no loss of a direct flap in 42 consecutive cases handled in this manner.

The pedicle base of the flap and the portion not directly applied to the defect but continuous from the base and pedicle up to defect, were covered with split thickness grafts at the time of the original elevation and application. This method, in effect a closed aseptic method, overcame the disadvantages of allowing the base of the flap to remain raw. It also made dressing easier.

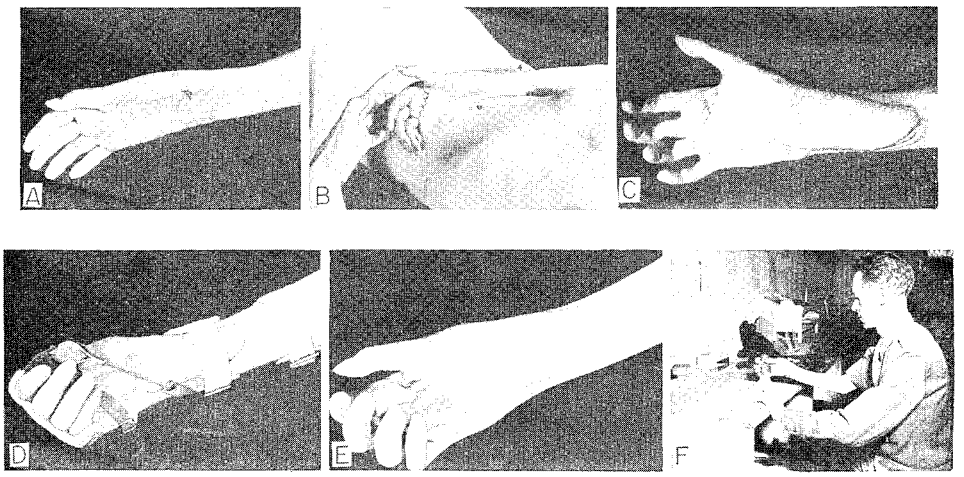



*Figure 98. A. Preoperative view of right hand following grenade explosion; split grafts have been applied. The bone is exposed and the only intact flexor structure in the wrist is the flexor ulnaris. B. Following excision of split graft, cicatrix, and necrotic exposed bone, a direct abdominal pedicle was created with a split skin graft applied to the abdominal base. Incision and delay of pedicle 2 weeks after application. C. Palmar view of hand and lower forearm, after release of pedicle. D. Postoperative splinting. Physical therapy was instituted in the interim between operations. E. Appearance of hand after revision of edges of pedicle, including Z-plasty of distal palmar edge, and tendon grafts to thumb and all fingers. Flexors of thumb were motivated by the extensor radialis longus and those of fingers by the brachioradialis. Opposition of thumb was accomplished by use of flexor ulnaris and adduction by means of a tendon loop from the external communis of the index finger. A median nerve graft and wrist fusion with an iliac bone graft were also carried out. F. Cosmetic and functional results. Note the grasp now possible.*

When the position and size of the defect required a flap of large size (Fig. 98 A) or greater length than the width of the pedicle base, flaps were used with incision and delay in stages.

The abdomen was the usual site of the donor flap, though small flaps from the chest were also used. A defect of the thenar area could be corrected by a flap from the opposite arm while increased spread of the thumb was simultaneously maintained (Fig. 99).

*Tube Pedicles.* It was not found necessary to follow anatomic lines of arteries and veins in setting up the original tube provided the ratio of 1:3 was maintained between the width and length of the pedicle to be used. Tubes of small size were closed underneath by direct approximation of the lateral margins of the donor area by the methods of Davis,[4] Gillies,[5] or Bunnell.[6] The

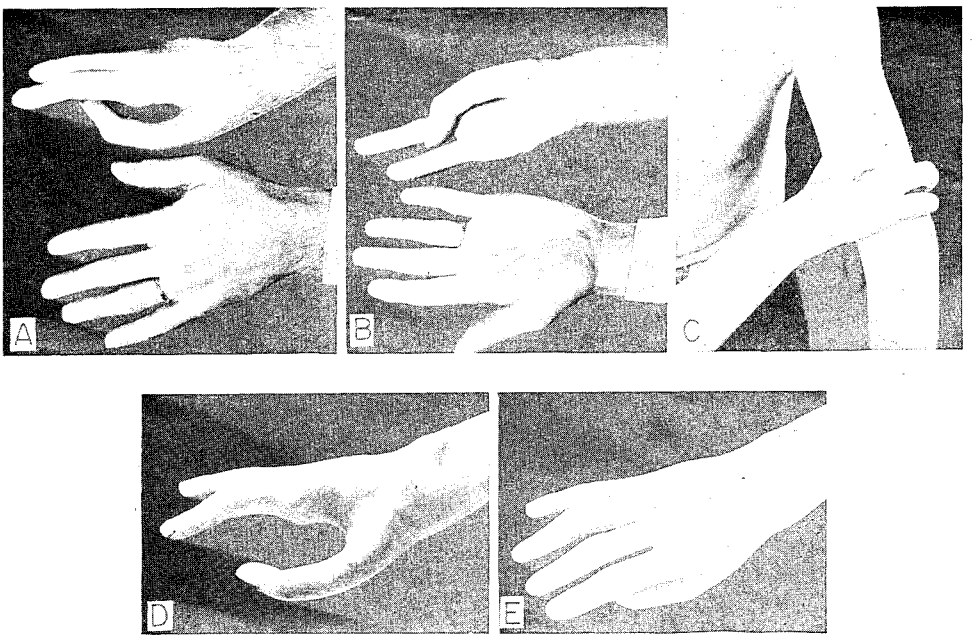



*Figure 99. Loss of rays of index and middle finger, cicatricial and fibrous contracture of thumb, partial median nerve anesthesia, and stiffness of thumb following gunshot wound of right hand. A. Preoperative dorsal view. B. Preoperative palmar view. C. Direct pedicle skin graft from opposite upper arm, following excision of cicatrix. A split thickness skin graft covers the base of the site from which pedicle was elevated. D. Appearance of hand following division of pedicle and occupational and physical therapy. Patient now has considerably increased motion in thumb and fingers. E. Latex rubber prosthesis supplied for cosmetic reasons.*

[4] Davis, John Staige: Plastic Surgery: Its Principles and Practice. Philadelphia, P. Blakiston's Son & Co., 1919.

[5] Gillies, H.: Practical uses of tubed pedicle flap. Am. J. Surg. 43: 201–215, Feb 1939.

[6] Bunnell, Sterling: Surgery of the Hand. Philadelphia, J. B. Lippincott Company, 1944, p. 185.

Bunnell method resulted in improved healing, particularly in the corners. When the tube pedicle was more than 2.5 inches in width, more satisfactory results were obtained by covering the base by a split thickness skin graft rather than attempting to approximate the lateral margins. This technique also permitted construction of larger, wider, and better nourished tubes and escaped the disadvantageous wide undermining and occasional formation of hematomas in the undermined areas. At the same time it increased the patient's comfort after operation.

At least 3 weeks were allowed to elapse before the division of one pedicle and its transfer application. Incision and delay of transfer of the base were practiced in some instances, though ordinarily the intermittent application of a rubber band about the end to be sectioned was sufficient. Incision and delay proved most satisfactory when a large flap was made on one end of the tube. This technique does not furnish a flap of exact size and configuration to fit such a defect as would be encountered in the palm. In some of the latter instances a short, thick tube was made, and the pattern of the opened defect of the recipient area made at operation was used to outline the shape of the pedicle end. The pedicle was then incised and transferred.

Concomitant use of a split thickness graft and adjacent pedicle often proved advantageous. A defect requiring pedicle skin on hand or forearm was often covered by swinging an adjacent pedicle over into place either directly or in stages. The site from which the pedicle was transported was immediately covered by a split thickness skin graft. Function of the donor area remained unimpaired if sufficient areolar or fatty tissue were left to receive the split graft and to permit adequate function of the subjacent parts. In selected cases bone grafting or joint operations could be done at the same time as the plastic procedure (Fig. 100).

## BONES AND JOINTS

*Fractures.* Fractures of bones were second in incidence only to cicatricial deformities of the skin and soft tissues. Metacarpal fractures were most common. Severe damage to muscles, tendons, nerves, and soft tissues was usually associated and deformity was likely to be marked.

Metacarpal fractures were managed by the use of a molded forearm and hand cast consisting of a curved aluminum splint placed on the volar aspect of the affected ray. The metacarpophalangeal joint was left free and elastic traction was accomplished by a pin through the distal phalangeal pulp or, occasionally, through the distal end of the bone of the proximal phalanx. Proximal and distal joints of the finger were maintained in a position of 45 degrees and the middle joint at 90 degrees flexion. Uninvolved fingers were not immobilized. If the fragments could not be held satisfactorily in alinement by closed methods, Kirschner wires were placed in two or more planes, their ends

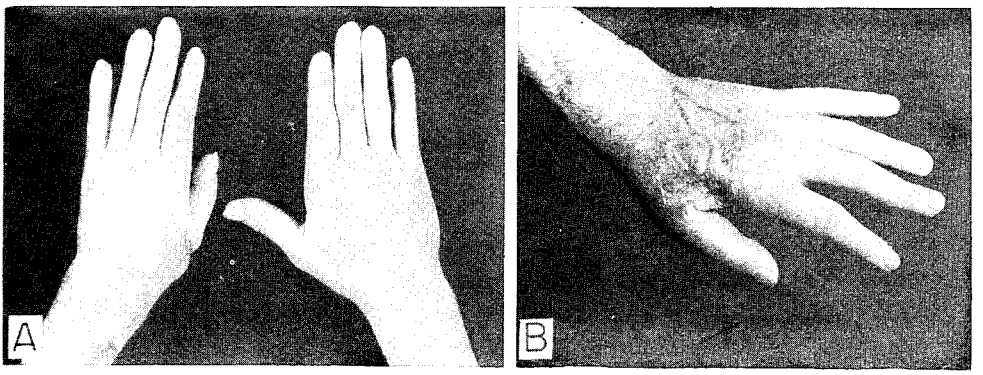



*Figure 100. Cicatrices in forearm adherent to long extensors of index finger of left hand; cicatrix on dorsum of thumb; fracture of metacarpal of thumb with nonunion and loss of substance; severance of short and long extensors of thumb. A. Preoperative view. Note limitation of spread of left thumb. B. Postoperative view, showing increased thumb spread following excision of cicatrix; rib bone graft to metacarpal of thumb; transportation of pedicle of adjacent skin and subcutaneous tissue to cover bone graft; and free tendon graft from the extensor of a toe. A split thickness graft was applied to the donor area of the pedicle. The operation was done in two stages.*

being cut off subcutaneously. Open wounds were covered with split grafts. This method gave excellent reduction without undesirable complications. A similar plan, without the use of traction, was employed for phalangeal fractures.

Fractures of the carpal bones, particularly if marked comminution had occurred, were treated by prolonged immobilization with the wrist in a functional position of dorsi-extension. As healing occurred, pain disappeared. Serial roentgenograms sometimes showed that healing took place in ununited fractures as long as 4 to 9 months after the injury.

If arthritic changes and bone comminution were present, carpal bones were removed in either the proximal or the distal row, with reduction and satisfactory mobility if the cases were properly selected. Wrist fusion was resorted to in 7 patients. This operation brings about relief of pain and provides the stability necessary for a manual worker.

Malunion and nonunion were observed most frequently in metacarpal fractures accompanied by shortening and loss of substance, and in phalangeal and carpal fractures. An occasional case could be treated by osteotomy and fixation with Kirschner wires, but usually a bone graft was required. These were of two types: (a) The key type, used when additional length was not necessary and the bone ends were not sclerotic, and (b) additional bone to provide for correction of length and position. Displacement of metacarpal heads into the palm, with consequent disruption of the intrinsic musuclar arrangement and of function often accompanied metacarpal fractures with malunion. This deformity

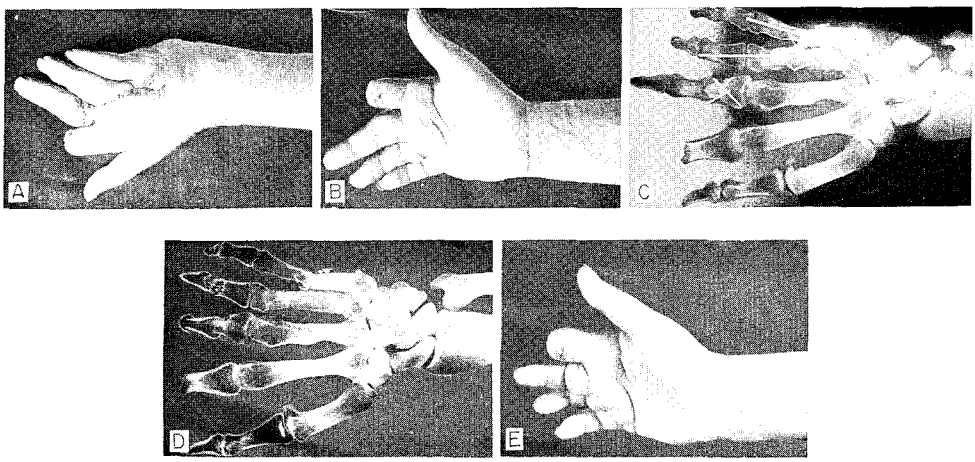



*Figure 101. Loss of index finger and severe injury of dorsal soft tissue structures and bones of hand by machine gun bullets. A and B. Preoperative dorsal and palmar views. The palmar structures are relatively uninvolved. C. Roentgenogram of hand following multiple bone grafts and arthrodeses with Kirschner wire fixation. The ilium was used as the donor site. D. Roentgenogram of hand following removal of fixation wires. E. Postoperative result. Hand is now stable and flexion is sufficient for grasp of large objects.*

was corrected by concomitant capsulectomy of the proximal joint when the bone graft was applied.

Fractures into interphalangeal joints with nonunion or malunion were treated by arthrodesis in the position of function or by amputation of the distal portion of the finger.

*Osteomyelitis.* Incidence of bone involvement in wounds of the hand was relatively high. Osteomyelitis was seen only occasionally. When observed, infection had usually been present for several months before the patient was received, most commonly with metacarpal fractures. Frequently several small sinuses were present, and bones were often exposed. Drainage was likely to be moderate and the systemic reaction minimal.

Treatment consisted chiefly of splinting in the position of function to afford rest and minimize deformity. Local applications were at first limited to the use of Dakin's solution and moist dressings saturated with boric acid or physiologic salt solution. Later, dry dressings and hand soaks were substituted.

If sequestra were observed in the roentgenograms taken routinely when the patients were first admitted, they were removed as soon as local inflammation could be brought under control. Penicillin was used intramuscularly before and after operation.

When amputation had to be undertaken in the presence of osteomyelitis, the operation was performed through a joint. The wound was lightly covered

with a flap of skin, which was occasionally held in place by a few wire sutures. These were loosely placed, and were tightened by twisting if there was no inflammation when the wound was dressed. Wound closure was thus readily accomplished.

When osteomyelitis involved the phalanges of the thumb, metacarpals, and adjacent joints, a conservative policy was employed. Roentgenologic evidence showed that bone which had previously been affected healed well after the extrusion of sequestra. This policy helped avoid amputation and kept thumb length as nearly normal as possible.

Five instances of osteomyelitis in which the bone was exposed were treated by removal of the necrotic bone surface and the application of a split thickness graft. In 1 patient the graft was applied at operation, and in the other 4 patients from 8 to 10 days later. In all 5 patients the grafts were partially successful and healing was accelerated.

In several instances in which a positive culture was secured from exposed necrotic bone but in which there was no evidence of surrounding inflammation, the involved bone was removed and a pedicle graft was applied at the same operation. In 7 cases in which the long bones of the forearm or the carpal bones of the wrist were involved, an adjacent pedicle or an abdominal pedicle was applied without postoperative wound infection. Penicillin was used before and after operation.

*Bone Grafts.* Bone grafting was done in 57 patients, with nonunion in 1 and delayed union in 3 others. Results were good in the remainder. Iliac bone proved most satisfactory for grafts used to repair metacarpal and carpal bones. Results were good in 7 cases in which grafts from the ulna were used, but an ulnar graft required 7 to 8 weeks for union and tended to lose substance in time, whereas union was observed as early as 5 weeks with iliac bone. Ribs (Fig. 100), as well as metacarpals or phalanges from amputated rays, were also used. Rib grafts, with a portion of cartilage on the end, were employed in a few instances in which total reconstruction of the thumb was necessary, and loss of bone substance at the distal (free) end was apparently thus prevented.

Insertion of Kirschner wires in at least two planes proved to be the most generally effective method for fixation of a bone graft (Fig. 101). The ends of the wires were bent and cut off subcutaneously. Concomitant capsulectomy of the proximal joints of the fingers was used in all cases except a few in which the distal end of the metacarpal bone was merely the shell of the metacarpal head.

Following capsulectomy and Kirschner-wire fixation of bone grafts, elastic traction was applied to the fingers to prevent stiffness and assist in the restoration of motion.

Iliac bone was found most suitable for grafts in wrist fusion, though in selected cases a section of the radius or the head of the ulna was preferred.

Bone grafts of the phalanges were limited to key grafts to secure stability in osteotomies or arthrodeses. These grafts were most often taken from the ulna. Tibial grafts were not used in this series of cases.

*Remobilization and Capsulotomy.* Remobilization was accomplished by both surgical and nonsurgical methods. Procedures invoked were applied chiefly to joints but also contributed to movement by muscles and tendons.

No surgical procedures for joint reconstruction were undertaken at, or distal to, the middle joint of the fingers. Experience showed that arthroplasty and capsulectomy on these joints were accompanied by instability and loss of function. The single exception was mobilization of a contracted middle or distal joint by stripping of the volar capsule; this was employed in 3 cases of reconstruction of the digits. Surgical mobilization was carried out prior to the application of pedicle skin and tendon grafts. In these cases the patient's desire to retain his finger was respected, but he clearly understood that only limited motion would be gained as the result of reconstruction. An increased range of motion (from 40 to 60 degrees) was obtained by the operation on the joint and on the restraining checkrein tendons.

Proximal joints of the fingers which were stiff in extension were treated by arthroplasty or capsulectomy. Arthroplasty was used when there was bony and cartilaginous destruction in the joint. The proximal or the distal articular bone (never both) was reshaped and covered with a fascial hood. Increased range of motion of 40 to 90 degrees were obtained and relief from pain achieved. Best results were obtained in the middle and ring fingers, because of the buttressing effects of the adjacent index and little fingers. Arthroplasty of the little or the ring finger was, however, equally satisfactory if the surrounding capsule and ligamentous structures were not too greatly involved.

Capsulectomy of the proximal joints was preferred to capsulotomy. The shortened lateral collateral ligaments were also excised. Results were uniformly helpful.

Both after capsulectomy and arthroplasty, part of the postoperative routine was immediate application of elastic traction, installed in the operating room and incorporated in the splint applied at the conclusion of the operation. Traction was maintained for 3 weeks or longer. Active motion was instituted 2 weeks after capsulectomy and 3 weeks after arthroplasty.

Arthroplasty at the base of the thumb was carried out in 9 patients, with beneficial results. When the thumb had been held in the flat hand position and motion was limited by fibrous ankylosis about the joint or by a restraining thenar contracture, the position was improved and a wider range of motion was obtained. The primary objective was to accomplish a position of opposition. If comminuted multangular bone was present, it was removed entirely and the thumb lashed to the navicular bone by passing a loop of tendon transversely through a hole at the base of the metacarpal of the thumb and through

another hole located anteroposteriorly through the navicular bone. Results from the standpoint of the position of opposition were good, and the range of motion was 10 to 30 degrees or more. When the joint surface of the metacarpal of the thumb was damaged, thin areolar fatty tissue (paratenon) or thin fascial tissue was inserted between the joint surfaces.

Mobilization procedures on the carpal bones were limited to excisions. Only in exceptional instances was arthroplasty of the wrist carried out. When, in some instances of radial-ulnar-carpal-bone injuries and infections supination-pronation movements were limited to a disabling degree by ankylosis, marked improvement could usually be obtained by excision of the ulna slightly proximal to its distal end. After the removal of 1 to 2 cm. of the ulnar shaft, a loop of tendon graft was passed around the proximal osteotomized shaft of the ulna and the flexor ulnaris tendon, to prevent dislocation of the shaft and the ulnaris tendon during supination and pronation. In cases presenting ulnar-carpal adhesions and damage to the radial-carpal joint, excision of the head of the ulna with fusion of the radial-carpal bones at the wrist achieved stability with the wrist in fixed dorsi-extension, and permitted retention of supination and pronation.

In hypermobility of the wrist, with dislocation of the distal end of the ulna, stability, with retention of mobility, was obtained by placing a loop of tendon around the distal neck of the ulna and fastening the ends into the lateral aspect of the distal end of the radius. In addition, a drill hole was passed through the head of the ulna and the ulnar triangular ligament was replaced by half of the distal end of the flexor ulnaris which was split and carried from its insertion up through the drill hole in the ulna. A further loop of tendon placed about the extensor ulnaris was fastened to the dorsal ligament of the wrist. This method, devised by Bunnell, was used in 3 patients, with certain modifications required because carpal bones were fractured. Results were good in all 3 patients and mobility was retained.

Mobilization by nonsurgical methods was chiefly accomplished by the use of corrective splints (Fig. 98 D). Attention has already been called to the use of constant elastic traction after operation, to provide actual strength and elongation by growth of contracted joint ligaments. Shortened tendons also responded to corrective splinting to a limited extent, though tendon lengthening operations usually had to be resorted to, especially in contractures of the Volkmann type. Muscle training following atrophy from disuse or in cases of returning nerve function and tendon transfer was the responsibility of physical therapists who were carefully instructed as to the exact operations performed in each case and the specific needs of the patient. Special devices were employed in occupational therapy to aid in overcoming contractures and to gain mobilization, particularly increased opposition of the thumb, extension of the wrist, and flexion of the fingers.

## NERVE AND VASCULAR INJURIES

If damage to the hand included even minor nerve and vascular disruption, there was frequently present during the first 6 months after injury a condition of vasomotor instability manifested by discomfort, coolness, an increased violaceous hue, and edema. These manifestations were more prominent if main vascular arches, median or ulnar nerves were totally divided. Joint stiffness was also associated.

Damage to nerves and blood vessels did not prevent reconstructive procedures on the hand if the level of division was in the palm. Amputation of digits was, however, occasionally necessary.

High vascular lesions, such as injuries of the brachial and axillary arteries, were likely to be accompanied by muscle atrophy, contractures, and Volkmann-like deformities. In a few selected cases of this type moderate correction was achieved by the use of cervical sympathetic block in the early stages, elastic corrective splinting, occupational and physical therapy, resection of carpal bones or wrist fusion, and tendon lengthening procedures.

It is known that repair of median or ulnar nerves in the lower forearm, wrist, and hand is accompanied by varying degrees of return of function. These are mixed motor and sensory nerves. Sensory function returns more rapidly than motor function. Experience has shown that return of median nerve function following suture in the lower forearm, wrist, and palm can be expected in about 65 percent of all cases and that return of motor function in the ulnar nerve occurs in about the same proportion of cases. A patient submitted to neurorrhaphy therefore stands about a 1:3 chance of having an unsuccessful motor result. Furthermore, if motor function does return, it may be only partially satisfactory in respect to the ultimate power of the innervated muscles, while even in successful cases 12 to 18 months are necessary before return is at a functionally useful level.

These considerations were the basis of the plan of treatment in such injuries. In 23 cases selected for operation because of marked atrophy of the intrinsic hand muscles, tendon transfer was performed concomitantly with neurorrhaphy as follows:

In 11 cases of damage involving the median nerve a tendon transfer to furnish opposition of the thumb was carried out at the time neurorrhaphy was done, or at a subsequent operative step in the reconstructive program.

In 9 instances in which the ulnar nerve was damaged at the wrist or in the palm, a tendon transfer to furnish interosseous and adductor function was carried out with the nerve repair. This procedure entailed either concomitant tendon transfer to furnish interosseous and adductor pollicis action, or tendon transfer soon after nerve repair. In 7 of the 9 an adductor T operation was performed, and in the other 2 a tendon loop was made to furnish adduction of the thumb. Ability to spread, oppose, and extend the two distal joints of all

330362 O—55——16

the fingers was accomplished by transfer of the proprius tendons of the index and little fingers, or transfer of the sublimis tendon slips to the lateral bands of the interosseous dorsal extensor mechanism, or by both procedures.

In 3 instances of combined median and ulnar nerve paralysis, restoration of intrinsic muscles supplied by median and ulnar nerves was accomplished by combined tendon transfer.

Results of the application of these principles were gratifying. All patients benefited by rapid improvement in function (Fig. 102). The possibility of failure of return of nerve function was compensated for in advance by the tendon transfers performed at the time of neurorrhaphy.[7] The 12 to 18 months ordinarily lost while waiting for nerve function to return were not blank periods in these cases for the patients had functionally useful hands. Corrective and protective splints could be discarded relatively soon after operation because the imbalance resulting from paralyzed muscles was compensated for by tendon transfers. In most cases the period of observation was too short to permit final evaluation but in 2 patients who were observed for a sufficient follow-up period (6 months), no secondary muscle imbalance occurred when nerve function returned. In each instance there appeared to be a continuous, even subconscious, adjustment of balance between the transferred tendons and the intrinsic hand muscles to which function was returning.

*Nerve Suture.* Many patients with nerve injuries at the wrist or distal to it, or with nerve injuries accompanied by tendon damage, were received from neurosurgical centers or directly from distribution points. In these cases in which there was intrinsic involvement of the muscles of the hand, electrical testing for the reaction of degeneration was inconclusive and variable; the small hand muscles could not be isolated individually by the testing machine. Clinical evaluation at the operating table, when the appearance and consistency of scarred but undivided nerves could be determined directly, was found to furnish more accurate criteria upon which to base the decision whether to perform neurolysis or to excise the scar and neuroma and resuture the nerve. Neurorrhaphy was accomplished by means of silk (No. 7–0) sutures on an atraumatic needle. This technique permitted accurate approximation of the sheaths of large as well as of very small nerves.

Because there was no administrative provision for hand centers to hold patients for observation following neurorrhaphy of nerves within the hand, end results could not be evaluated in most cases. In 8 patients, however, in which neurorrhaphy of the median and ulnar nerves at the wrist was followed by other surgical procedures, a 4-month period of observation was possible. In 7 of these sensory return was observed during this time. In the eighth patient, in which no return of function was observed, a second operation was

[7] To add tendon ⊤ and muscle balance operations to suture of median and ulnar nerves is regarded as too radical. These operations may be done later if nerve sutures are not successful.—Ed.

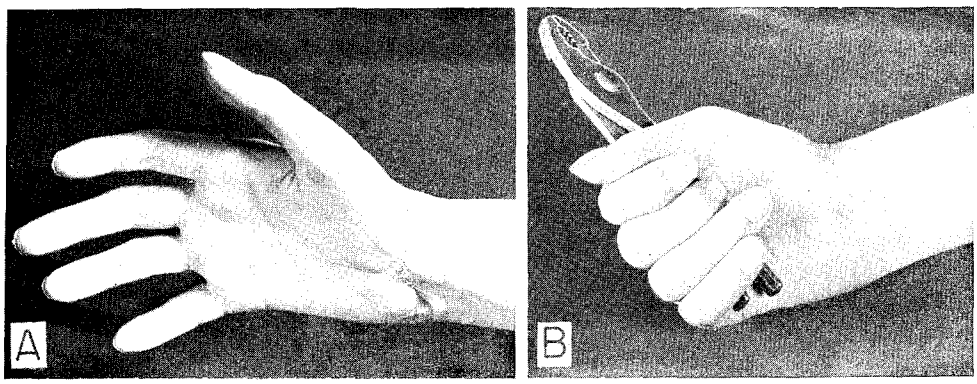



*Figure 102. Combat-incurred injury resulting in division of long flexor tendons of little finger, partial division and adherence of other flexor tendons of thumb and fingers, division of the median nerve with neuroma formation at the wrist, division of the motor ulnar nerve at the hypothenar level, atrophy of the intrinsic muscles supplied by the median and ulnar nerves, numbness over the distribution of the median nerve, and inability to flex and extend the thumb and fingers freely. The usual claw hand observed in ulnar motor paralysis is absent in this case because of severance of the long flexor tendons and resultant lack of pull. A. Preoperative view of hand. B. Postoperative view showing functional result. At this time the patient could hold a glass of water, write (crudely) with a pen, hold a knife or fork, and spread and approximate the fingertips. Deep sensation was present at the tips of all fingers 110 days after operation; sensory return was first perceived on the 77th day. The reparative procedures, performed in a single stage, were as follows: Excision of the cicatrix; neurolysis and tendolysis at the wrist; excision of a glioma and neuroma from the median and motor ulnar nerves respectively; neurorrhaphy of these nerves; multiple tendon transfers and multiple grafts secured from the long extensors of the foot. The tendon from the tip of the thumb to the wrist was replaced by a graft of the flexor pollicis longus. The distal end of the flexor profundus tendon of the little finger was transferred into the flexor profundus of the ring finger. An opposition transfer of the extensor pollicis brevis was motivated by the palmaris longus and carried through a pulley constructed from the distal half of the flexor ulnaris. An adductor tendon T was carried out with a crossbar tendon graft from the thumb to the metacarpal of the little finger and was motivated by the sublimis of the ring finger. The sublimis of the index finger was split in three and transferred to the lateral band of the dorsal extensor apparatus on the ulnar aspect of the index, middle, and ring fingers. The sublimis tendon of the middle finger was split in four and transferred to the lateral band of the dorsal extensor apparatus on the radial side of the index, middle, ring, and little fingers. A paratenon graft was applied about the structures in the wrist. A volar carpal ligament was constructed from a loop of tendon.*

done. The pathologic preparation showed scarring, also some nerve fibers passing through the site of operation. Returning sensation was generally apparent within 6 weeks after operation, the rate of progression sometimes being as much as 2 inches per month instead of the usual rate of 1 inch. Critical analysis for the factor of overlap in the evaluation of sensory return was not usually carried out. This factor was evaluated by block of the adjacent undisturbed nerve supply under local analgesia, as, for instance, blocking the uninvolved ulnar and radial sensory nerve in order to estimate the true return of sensation in a sutured median nerve.

The policy of concomitant nerve and tendon repair and transfer has been discussed elsewhere in this chapter.

*Nerve Grafts.* Nerve grafting was carried out only with autogenous grafts. In 7 instances a sensory digital volar nerve was replaced by a graft of volar nerve secured from an amputated finger or a segment of the sural nerve in the region of the ankle. Silk (No. 7–0) sutures were used. Sensation returned in 5, but not in the other 2.

In 5 patients cable grafts constructed of 2 or 3 strands of sural nerve were used to bridge gaps of 5 to 6 inches in damaged median or ulnar nerves (Fig. 98 E). One patient in this group was followed up for 7 months and another for 6 months (the remainder were observed for 5 months or less) but in no instance did sensory return occur. In the patient followed up for 7 months resuture of the distal end of the cable graft was carried out at the end of this period. The pathologist reported that the excised area of the former suture showed nerve fibers, but he could give no further information in regard to down growth. The patient followed up for 6 months also had a resuture of the distal end of the graft at the end of this period, with concomitant tendon transfer to provide opposition of the thumb.

In a patient treated by homogenous sciatic nerve graft, removal of the graft was carried out when he was readmitted 3 years later. It was found grossly scarred and histologically free from nerve fibrils. In 1 instance of ulnar nerve defect in which the median nerve was normal, transfer of the sensory branch of the radial nerve into the distal end of the ulnar nerve was followed within 11 weeks by increased sensory return up to the base of the little finger. Since the original lesion was of more than a year's duration, the sensory return was not considered overlap from the median nerve. The resultant anesthesia of the radial-sensory nerve supply (to the dorsum of the hand) was limited to total anesthesia in the isolated area of supply between the thumb and index fingers and to slight paresthesia of the surrounding area insufficient to constitute a functional disability in itself. Transposition of the sensory branch of the radial nerve into the median nerve was not practiced because of the undesirable results likely to follow, namely, loss of overlap in a wide area of the distribution of the two adjacent nerves.

*Neuromas Following Operation.* In most instances painful amputation stumps of the upper extremity including the palm and distal to it were those which had been cared for under emergency conditions, and records revealed no direct treatment of the nerves at the time of the original operation. Relief from pain was secured in these patients by revision of the stump, removal of neuromas, ligation of the end of the nerve with sutures of fine material, and injection of the distal centimeter of the nerve with absolute alcohol.[8]

Neuromas were not clinically apparent until 2 to 3 months after amputation, and the painful amputation stump therefore did not become a problem until the patient had been evacuated to the Zone of Interior or returned to duty. There was a known recurrence of painful neuromas in 3 percent of the patients treated by revision of amputation, but the great majority were not followed up and the value of the measures employed is therefore not known.

## TENDON REPLACEMENT

Of a total of 823 procedures performed, 133 were directed at tendons (Table 12). Many of these 133 were multiple. As many as 6 tendon grafts were placed in the same hand at a single operation, and 8 or more tendon transfers were carried out concomitantly (Fig. 102). The figure 133 thus does not represent the true incidence of tendon operations. Tendon replacement was frequently performed with other plastic procedures which permitted the mobility necessary for postoperative care in tendon operations.

Tendolysis was the procedure most frequently performed alone, or in conjunction with other procedures. In most of these, reformation of adhesions was prevented by the insertion of a sliding graft or delicate areolar fatty tissue (paratenon) taken from the lateral aspect of the thigh or from above the elbow. A section of fascia from the forearm was sometimes similarly used.

Only autogenous tendon grafts were employed. They were secured from amputated fingers, sublimis tendons, and the long extensors of the toes. No fascial grafts were used.

Suture with the silk technique of Mason and Allen [9] was usually employed. This technique, which satisfies physiologic considerations, gave generally good results. Excellent results were also secured with the stainless steel wire pullout method of Bunnell [10] which was used whenever mutiple tendon grafts were placed. It is a speedy method and as many as 8 tendon transfers and 4 tendon grafts can be performed at a single operation.

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[8] To prevent a neuroma from becoming painful the nerve should be cut off in good tissue not in cicatrix. It has been found unnecessary to ligate it or inject alcohol.—Ed.

[9] Mason, M. L., and Allen, H. S.: The rate of healing of tendons; experimental study of tensile strength. Ann. Surg. 113: 424–459, Mar 1941.

[10] Bunnell, Sterling: Surgery of the Hand. 2d ed. Philadelphia, J. B. Lippincott Company, 1948. pp. 419–431.

It was possible to evaluate the results in 93 of the tendon grafts performed. In 7 instances the results were poor. In the other 86 increased function of varying degrees was secured (Fig. 103). Satisfactory useful function sometimes developed as soon as 3 months after operation, but as a rule maximum return did not occur for 18 months.

As the following typical cases show, tendon transfers were used extensively:

In 2 instances of radial nerve paralysis at or above the elbow, the flexor ulnaris was transferred to activate the long extensors of the middle, ring, and little fingers. The flexor radialis was transferred to activate the thumb and index finger, the palmaris longus to activate the long abductor of the thumb. Results were satisfactory in both.

In 3 instances of radial paralysis of the ramus profundus, with sparing of the nerve supply to the brachial radialis and long radial extensors, half of the extensor radialis longus was used to activate the abductor of the thumb while the radialis brevis was used to activate the long extensors of the thumb and fingers. Results were satisfactory in all 3.

In addition to tendon transfer for median and ulnar paralysis in the lower forearm, wrist, and hand, which has already been discussed, tendon loop was performed in 2 patients to furnish adduction of the thumb. The results were fair but by no means as good as results obtained with the adductor **T** operation. The tendon loop method was used in both of these patients only because there were insufficient flexor motors to activate an adductor **T** operation. The extensor communis was divided at its distal insertion, lengthened with a tendon

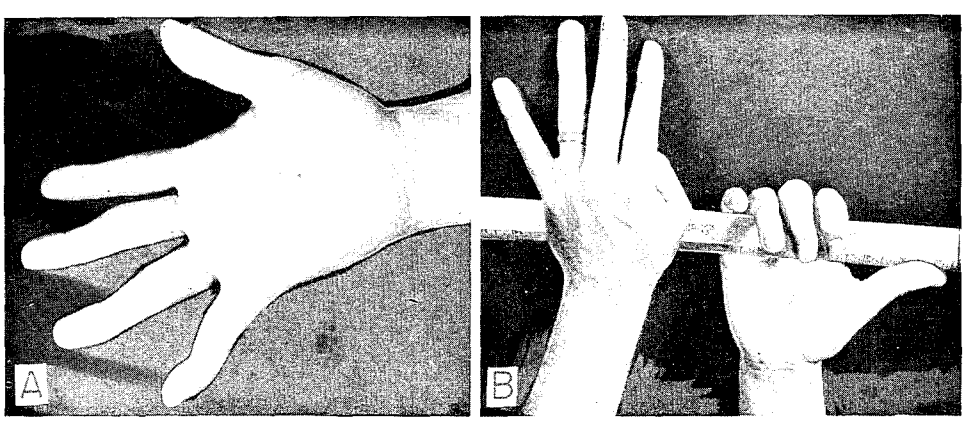



*Figure 103. Laceration of palm and division of sublimis and profundus flexor tendons of middle, ring, and little fingers, with resulting flexion disability of middle and distal joints. A. Preoperative view of right hand. B. Postoperative functional results. The sublimis tendons were used as grafts to prolong the profundus from the palm to the tips of the fingers. The palmaris longus was used in the little finger instead of the small sublimis. Pulleys created from loops of tendon were placed about the phalangeal bones.*

graft, carried from the level of the wrist around the dorsum of the hand and over the hypothenar muscles beneath the flexor structures of the palm, then attached at the midlateral ulnar aspect of the proximal phalanx of the thumb.

The adductor T operation was usually carried out by the standard technique: A free tendon graft from the ulnar-lateral aspect of the neck of the fifth metacarpal was carried beneath the flexor structures of the palm and attached to the ulnar side of the base of the proximal phalanx of the thumb and the longitudinal portion of the T by the sublimis of the ring finger. A variation of this technique which sometimes proved effective was to divide the extensor pollicis brevis at its musculotendon junction in the forearm, withdrawing it but leaving it attached at its insertion, and carrying it over into place as a crossbar. This variation does not hinder the action of the extensor pollicis longus and allows the construction of the crossbar of the tendon T with one less suture and one less graft.

Tendon transfer for opposition of the thumb was carried out by transferring the extensor pollicis brevis in the manner described, then carrying it subcutaneously across the volar surface of the thumb in the direction of the pisiform bone and attaching it in the forearm to an appropriate motor tendon. The pulley was constructed from a tendon loop by passing the tendon around the flexor ulnaris or by making a loop of the distal end of the flexor ulnaris.

The palmaris longus, the sublimis, and the brachioradialis were all used with satisfaction, but the flexor ulnaris proved to supply the most motor power.

The sublimis tendons and the proprius extensor tendons of the index and little fingers were sometimes transferred into the lateral extensor bands of paralyzed interosseous muscles. In 23 instances in which these procedures were employed for the re-establishment of intrinsic muscle action in the hand, improved function occurred in all. Careful muscle training on the anatomic basis of the tendon transfers was part of the postoperative routine.

Tendons which had not been sutured or grafted were mobilized early in the postoperative period. Protective splinting was maintained for 4 or 5 weeks after tendon suture, whether or not a graft had been used, and motion was not permitted until 3 weeks after operation.

## AMPUTATIONS

Extensive loss of circulation was regarded as an absolute indication for amputation of a digit. Involvement of any other single tissue, whether skin and subjacent tissue, nerve, bone, joint, or tendon, was considered reparable if the damage was not too extensive. When 2 or more tissues were involved, amputation was frequently found advisable, particularly if the damage was limited to a single digit. The thumb was the exception to this rule. It was preserved in its available length in every case in which the circulation permitted some type of reconstruction. When 2 digits were involved, even though

the extent of the damage was considerable and the tissues involved numbered more than 2, both were seldom amputated, and 3 were removed only when deficient circulation required it. In addition to the extent of the damage, the occupation of the patient influenced the choice for and against amputation.

It was usually the practice to preserve all possible length in a digital phalanx except for the distal cartilaginous tip. If the level of amputation necessary fell within the proximal third of the phalanx, however, elective amputation was carried out in the adjacent proximal joint, with removal of the cartilaginous portion of that proximal bone.

When amputations of the index or little finger were performed at the level of the proximal joint, the head of the metacarpal was preserved except for its cartilaginous covering. If the patient's occupation made digital dexterity or cosmetic appearance important, the amputation was carried out obliquely at the base of the metacarpal.

Amputation of the long or ring finger was never performed as a final procedure proximal to the metacarpal head, because crossing of the finger resulted if the metacarpal head had been lost or could not be preserved. To prevent this one of two procedures was employed: Excision of the ray or substitution of bone from a phalanx for the metacarpal head. When only a proximal portion of the metacarpal of the middle or ring finger existed, the ray of the ring finger was removed entirely. The metacarpal base of the little finger was then shifted over into the position of the ring finger, the tendinous attachments of the extensor ulnaris to its base being retained. When the middle finger ray was excised, the most proximal portion of the base of the metacarpal was preserved. Osteotomy was performed at the level of the proximal portion of the index metacarpal, which was shifted over onto the metacarpal base of the middle finger and held there with Kirschner-wire pin fixation. The end of the metacarpal, especially if the index metacarpal was involved, was shaped into a blunt wedge and the metacarpal base of the middle finger mortised appropriately. Bony union was good in all 3 cases in which this technique was employed. Advantages of this method of shift are that it closes up the hand, prevents crossing of the fingers, and allows insertions of the extensors of the wrist to remain intact and functioning.

In 3 cases in which damage to the middle finger ray included loss of the metacarpal head, a substitution procedure was carried out. The remaining portion of the metacarpal shaft was exposed and notched. The base of the proximal phalanx was similarly shaped and held in apposition to the metacarpal bone with a loop of stainless steel wire. Excess phalangeal tissues were removed following bony union.

The tendons of digits amputated at or proximal to the metacarpal head were sometimes drawn into the wrist and transferred at this level to other long flexor tendons to give increased strength to the remaining digits. Extensor

tendons were pulled up and cut off at a level which would allow them to recede proximal to the dorsal carpal ligaments.

Experience demonstrated that the best cosmetic results were accomplished by excision of the ray, while substitution preserves the breadth of the palm. Both techniques provide satisfactory function.

## RECONSTRUCTION OF DIGITS

Four total reconstructions of the thumb were done. In each instance the procedure was presented to the patient as an elective one. Many other patients with missing thumbs were offered reconstruction but did not desire it. While it was thought that the function of the hand was improved by this operation, there were certain disadvantages one of which was the length of time required for the procedure and the necessity for special care of the reconstructed part after operation (Fig. 104).

The first step of the procedure was the transfer of a prepared tubular pedicle to the base of the thumb. No bone was inserted until the tube had been detached from the donor site and was well healed in the recipient site. Only the rib was used for the bone in a reconstructed thumb, because the distal end of a graft from this area could be prepared so as to carry a cartilaginous tip from the costochondral junction and spontaneous resorption of the bone graft could be guarded against. Another advantage of the rib graft was that the shape of the rib provided a curve resembling that of the slightly flexed thumb, while its rotary curve favored the position of opposition. The graft was placed

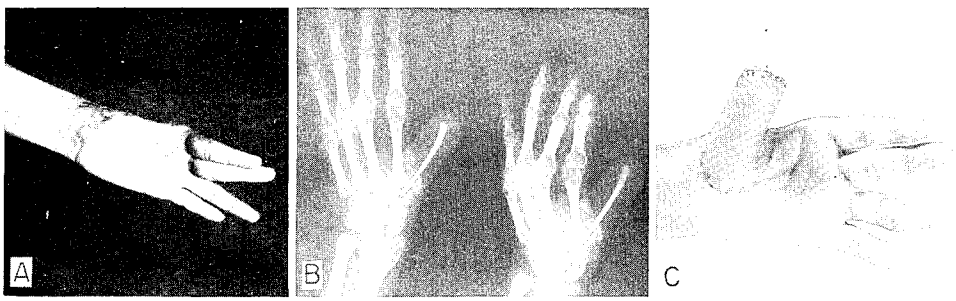



*Figure 104. Reconstruction of left thumb following battle-incurred loss. A. Preoperative view of left hand showing traumatic amputation of thumb through base of metacarpal. B. Roentgenogram following application of abdominal pedicle tube graft to the thenar area, with implantation of rib graft through the core of the pedicle and remains of metacarpal base into the greater multangular bone. C. Postoperative result. The rib graft and pedicle were subsequently shortened. At the conclusion of the restoration of the thumb this patient had sufficient mobility of the greater multangular, navicular, and radial joints to bring the new thumb into position so that pinch with the index, long, and ring fingers could be accomplished.*

into the greater multangular bone. In 2 of the patients in which total reconstruction of the thumb was undertaken a small portion of the metacarpal base remained. In these the bone was pegged through the metacarpal fragment and into the greater multangular bone.

The patients submitted to total reconstruction of the thumb were instructed to wear a hard leather cap over the new digit for the next 2 years whenever they were at work, in order to spare the insensitive pedicle from undue trauma until sensation had developed.

Partial defects of the thumb and other digits were repaired in a number of cases by application of a pedicle to restore the fingertips or the padding. In 5 instances in which patients with damaged digits declined amputation and in which reasonable improvement could be expected from reconstruction, tubular pedicles were applied to the volar surface of the digit to replace the defect of the scar and damaged tendons. Fingers in which amputation had been necessary below the distal third of the proximal phalanx were often supplied with phalanges by transposition of flaps across the web and insertion of small free grafts. This procedure was particularly useful in defects of the thumb, in which the graft could be inserted into the web. When amputation of the thumb had been performed at or distal to the metacarpophalangeal joint, the stump was regarded as of sufficient length without the addition of a pedicle or bone graft, and only phalangization, with a moderate recession of the abductor insertion proximally, was carried out.

*Transplantation of Digits.* Transplantation of digits was usually performed by use of an excised ray or shift of adjacent rays. In 3 patients in which only the thumb and 1 other digit remained, a transplantation was done, with rotary fixation of the remaining digit to secure pinch and grasp between the thumb and the remaining finger (Fig. 105).

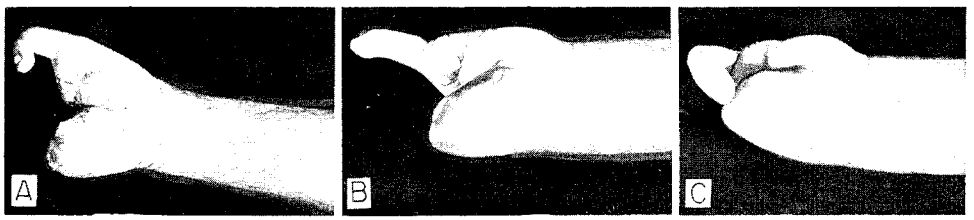



*Figure 105. Loss of index, middle, and ring finger rays and of distal phalanges of thumb; cicatricial deformity, adhesions of flexor and extensor tendons of little finger. A. Preoperative view of left hand. Pinch grafts were applied overseas in the cleft of the hand. B. Postoperative appearance of hand following single-stage reconstruction which included excision of cicatrix, shift and rotation of base of metacarpal of little finger with fixation onto the metacarpal base of the ring finger, revision of skin flap, tendon transfer, tendolysis, and excision of neuromas of digital nerves. Before operation, attempt to pinch with the thumb and remaining finger was ineffective and painful. C. Postoperative pinch movement effective and painless.*

In 2 patients pollicization of the index metacarpal was undertaken after partial amputation of the index finger. Operation was done in a single stage in the first case (Fig. 106), but in the other it was performed in multiple stages because concomitant repair of other damage in the hand contraindicated transplantation when the pollicization flaps were incised.

## PROSTHESES

Experience with prostheses was limited. Patients who had had amputations at or proximal to the base of the hand were referred to an amputation center. An occasional patient was supplied with a prosthesis for esthetic reasons. One such patient, a jeweler, who felt that his economic life would be hampered by the fact that the long and index finger rays were missing, was supplied with a latex molded prosthesis entirely for cosmetic purposes (Fig. 99). In another patient in whose hand only the ring and little fingers remained, these rays were stabilized, tendons were transferred to give good wrist function, and a prosthesis supplied to provide pinch (Fig. 107). As a rule, however, major prostheses were not provided.

## REHABILITATION

Rehabilitation after operation was begun in the dressing room on the ward. The status of reconstructed tendon grafts and transfers and of repaired nerves was explained to each patient and the precautions necessary were outlined when mobilization was begun. All patients were supplied with small wooden blocks to use in moving their fingers, and instructions for their use were given by the medical officers on the ward, who made frequent checks to see that they were being employed properly.

Initial mobilization and muscle-training procedures were carried out in the physical therapy department. Whirlpool therapy was found to be particularly effective for initial treatment.[12] The patients were instructed to move their hands during treatment, to carry out flexion exercises with the fingers, and to move them through prescribed ranges, under supervision.

In the occupational therapy department great reliance was placed on the use of sand blocks and other wood carpentry. Emphasis was placed upon mobilization and regaining strength rather than upon special occupational or adaptive training which it was felt could be obtained when the patient was transferred to a convalescent center after he had learned ordinary uses of his hand. His time in a general hospital was limited, and the acquiring of skills was considered secondary to mobilization and strength.

[12] There was no unanimity of opinion on the efficacy of the whirlpool bath in the treatment of injured hands as other chapters show.—Ed.

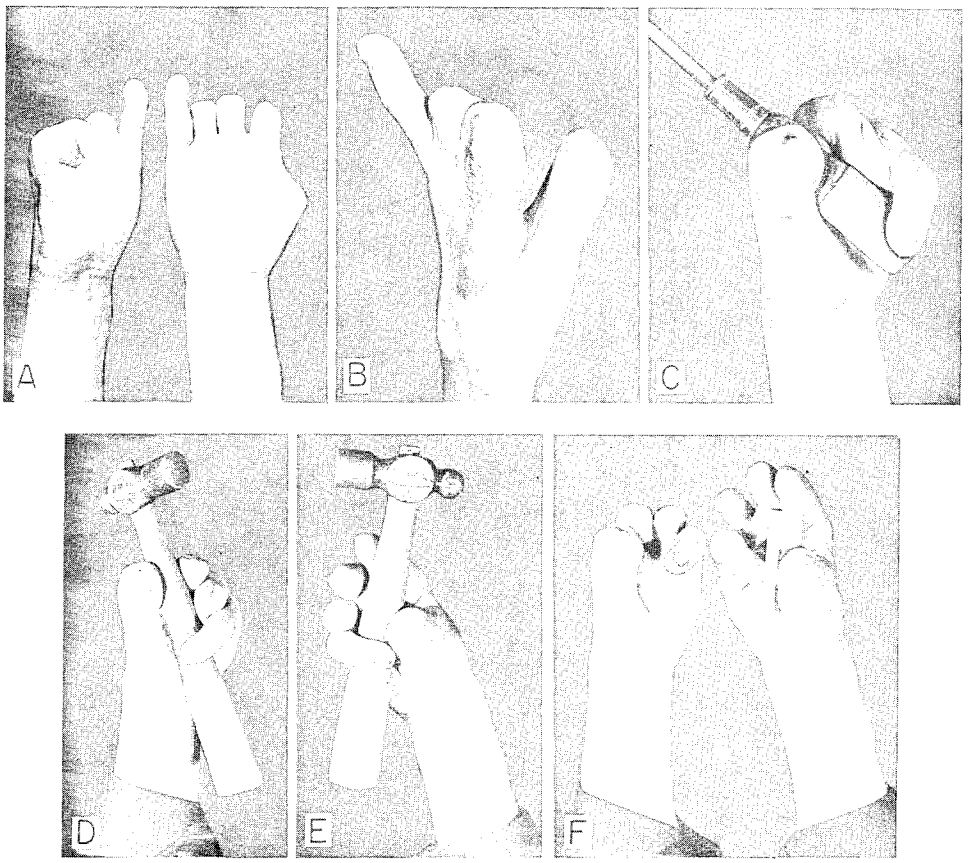



*Figure 106. Deformities of both hands following battle-incurred wounds. The left hand lacks the thumb, index, middle, and ring fingers above the level of the proximal joints. The greater multangular bone, much of the substance of the intrinsic muscles of the hand, and the tendons of the thumb were present, in part, in the scar. The amputations of the digits on the right hand occurred at a more distal level. A. Preoperative view. B. Postoperative view of right hand, following pollicization of index ray, a small portion of the proximal phalanx of which was present and permitted some flexion. The base of the index metacarpal was lashed with a tendon passed transversely through drill holes in the base and through the multangular bone anteroposteriorly. The abductor tendon of the missing thumb was fastened to the base of the transplanted metacarpal, and the flexor pollicis longus and extensor pollicis longus were transferred into the long flexors and extensors of the index finger respectively. Sensation was preserved by transportation of the radial half of the communis volar nerve to the index and long fingers, along with the shift of the index ray. Phalangization of the middle-ring and ring-little finger webs, with rotary osteotomy of the metacarpal of the little finger, was carried out to allow pinch between the little fingertip and the tip of the transported index ray. C–F. Functional possibilities of the reconstructed right hand. The left hand was similarly reconstructed while the operations on the right hand were in process.*

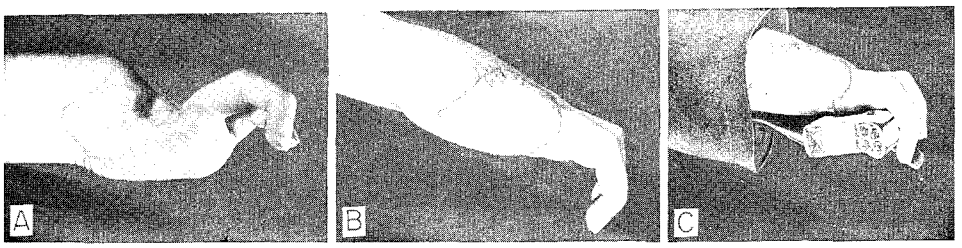



*Figure 107. Combat-incurred injury of left hand consisting of loss of thumb, index, and middle finger rays and proximal adjacent carpal bones; severance of the median nerve at the wrist, with resulting anesthesia of the radial aspect of the ring finger; fracture and loss of substance of base of ring metacarpal; hyperextension deformity of proximal joints of ring and little finger; adherence of flexor and extensor tendons of ring finger. A. Preoperative view of hand. B. Postoperative view following application of abdominal pedicle, excision of neuroma of median nerve with neurotomy, tenotomy of adherent tendons on radial side of wrist, transfer of tendons to base of ring finger to provide radial stabilization of wrist and increased dorsi-extension and flexion, tendolysis of adherent flexor and extensor tendons of ring finger, insertion of paratenon graft under these tendons, fixation of metacarpal of ring finger by implanting it into a hole drilled in the carpal bone, and capsulectomy of ring finger. C. Functional result. The patient now has increased strength and mobility in the hand, and is able to pinch and grasp with the aid of a simple volar prosthesis.*

After the initial therapeutic and educational stages work furloughs were found to be most helpful, especially for patients who required definite time intervals between various operative stages. No work furloughs were given after the final operative step. When a patient no longer needed either specific supervision by a medical specialist or corrective splinting, he was transferred to a convalescent hospital, or other appropriate disposition (duty or discharge) was made in his case.

CHAPTER VIII

# Hand Surgery at Crile General Hospital

*Gilbert L. Hyroop, M. D.**

## ADMINISTRATIVE POLICIES

When the plastic surgery section at Crile General Hospital was activated 12 February 1945, a hand ward was made part of it. Within the first 5 days 35 patients with hand injuries were transferred to this ward, and between that time and 5 December 1945 some 550 patients had been treated.

As in other hand centers, segregation permitted the close correlation of the three specialties required in the management of hand injuries—orthopedic, plastic, and neurosurgery. In addition to facilitating medical and surgical care, segregation was advantageous in simplifying adequate reconditioning, also occupational and physical therapy; again, it expedited the preparation and issuance of braces. Still another advantage was the opportunity offered for group instruction. Cooperation of the patient was essential in the management of hand injuries; cooperation was always better, and better end results secured, when soldiers with these injuries were cared for in groups.

## QUALIFICATIONS AND TRAINING OF PERSONNEL

The medical officer in charge of the hand section had had special training in the management of hand injuries while serving as resident, and chief resident surgeon, under the Civilian Consultant in Hand Surgery. The first officer assigned to the ward with him had had no special training, but at the end of 2 months had become sufficiently experienced to undertake skin grafts and the construction of tube pedicles and flaps. Before his 9-month period of service was concluded he was able to undertake bone grafts, and nerve and tendon repairs. Another officer later assigned to the service had had 6 weeks training at the Wakeman General Hospital Hand Center. The remainder of the surgeons received their training on the ward. Ward officers often cared for as many as 100 patients at one time.

The training program included formal lectures on the orthopedic, neurosurgical, and plastic aspects of hand surgery. Staff members met once weekly to discuss the cases to be submitted to operation the week following, and twice weekly, at night, staff conferences were held for the presentation of new patients and of those returning from furloughs.

*Instructor in Surgery, University of Oklahoma School of Medicine. Formerly Lt. Colonel, MC, AUS.

## SURGICAL PROCEDURES

Between the activation of the special hand service 12 February 1945 and its deactivation 7 December 1945, hand surgeons at Crile General Hospital performed more than 600 operations in various combinations. These included 87 bone grafts; 25 arthrodeses; 17 finger transplantations, with and without metacarpal transfer; 19 arthroplasties; 149 tendon repairs, grafts, and transplants; 162 skin grafts; 220 nerve repairs including suture, transplantation, and neurolysis; 7 fillets; 48 tube pedicles; 25 direct flaps; and 26 single-stage pedicle operations. The Civilian Consultant in Hand Surgery, Dr. Sterling Bunnell, assisted in the planning of these difficult surgical procedures in this highly specialized field, so that combinations of operations could be done concurrently.

## RECONSTRUCTION PROBLEMS

As soon as a patient was admitted to the hand service, a full history was taken, a physical examination made, routine and special laboratory work done, roentgenograms taken and consultations requested, if necessary. All patients were seen by the chief of the hand service who made a complete examination, recorded the diagnosis, and delineated the procedures and surgery recommended. The case was then discussed at a staff conference. Whenever a backlog of cases existed, the patient was given leave within 48 hours after his arrival on the ward.

In examination of the hand the origin of function of the entire extremity to the cerebral cortex was never overlooked. Cicatrices, deformities, ankyloses, and amputations were listed, as were vascular changes. A complete neurologic examination was made and sensory paralysis indicated (in red) on the worksheet made for each patient (Figs. 108 and 109). This worksheet contained a life-sized drawing of the injured hand or of the whole upper extremity, if necessary, the complete diagnosis, the list of procedures planned, and the list of those carried out. A glance at it just before operation quickly enabled the surgeon to recall the nature of the injury and the measures devised to correct it. Photographs of all injured hands were made before and after surgery.

## TYPES OF INJURY

Wounds experienced by most of the incoming patients had healed completely, having occurred from 3 to 12 months earlier. Approximately 85 percent had sustained compound injuries from high velocity missiles and shell fragments which had produced penetrating and perforating wounds characterized by destruction of skin, tendons, muscles, nerves, and blood vessels, and by shattering of the bones. Damage involved not only surface structures but extended to some depth in surrounding structures. Infection and osteomyelitis

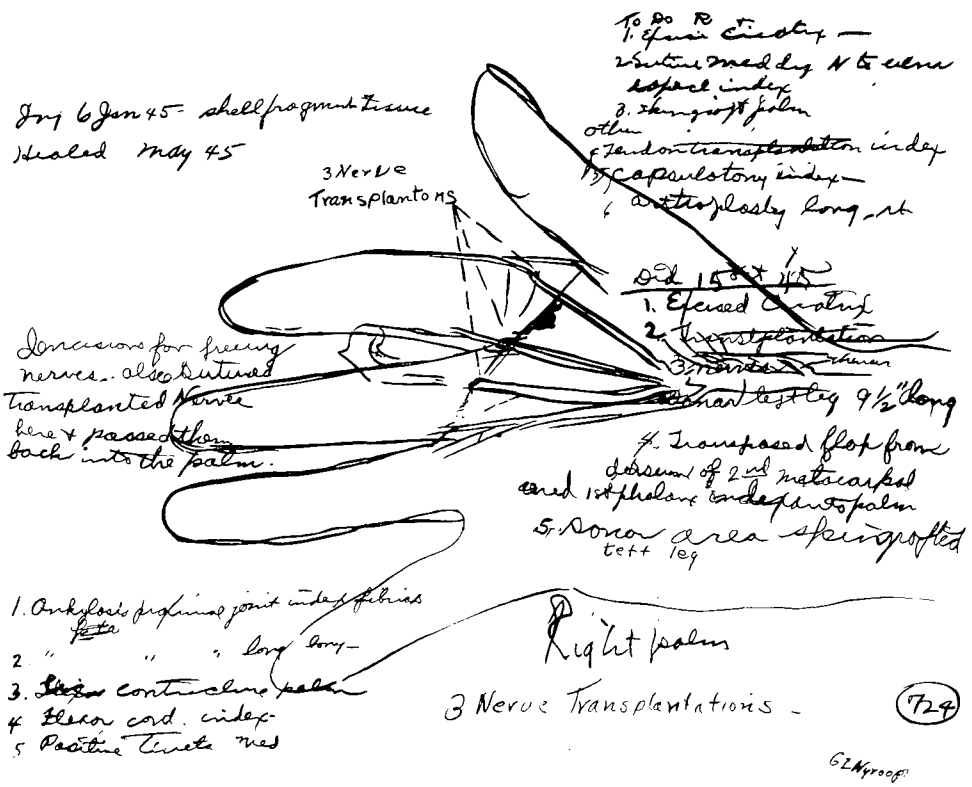



*Figure 108. Typical worksheet for patient with injury of right hand from shell fragments. When this soldier was admitted he had a cicatrix 1½ by 2⅛ inches on the palm; median nerve paralysis of the middle and index fingers; flexor contraction; atrophy of the ring, middle, and index fingers; ankylosis of the proximal joints; malunion of the head of the third metacarpal with disarrangement of the metacarpal head and of the articular end of the first phalanx, resulting in destruction of the joint. Loose fragments were present in the fracture site.*

*At operation the cicatrix in the palm over the head of the second metacarpal was excised. A flap was raised on the radial aspect of the head of the second metacarpal and the first phalanx of the index finger and transposed into this area at the time of closure. The donor area was skin grafted; skin 0.22 inch thick was removed from the right forearm for this purpose. The cicatrix was dissected from the lateral to the medial aspect of the hand and a tendolysis of the long flexors, with removal of all scar tissue, carried out. The median nerve to the index finger and the lateral aspect of the long finger was found entirely destroyed; there was a gap of about 2½ inches between the proximal and distal ends. A piece of the sural nerve 9½ inches long was removed from the left leg and used to furnish three nerve transplants to the index and middle fingers; the transplants were sutured end to end with No. 5–0 and No. 6–0 black silk. The flap was closed with stainless steel wire and the skin sutured with No. 3–0 black silk. A pressure dressing with a plaster of paris splint was applied with the hand in the position of function.*

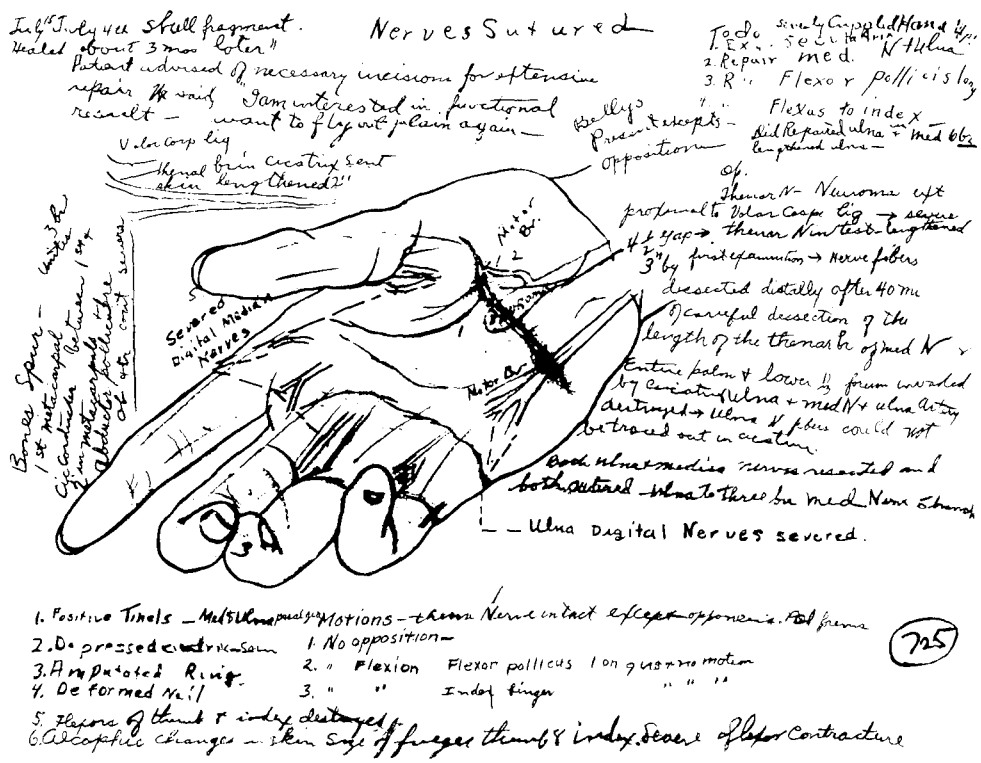



*Figure 109. Typical worksheet for patient with injury of right hand caused by shell fragment. When this soldier was admitted he had a cicatricial deformity of the palm in the form of a transverse cicatrix 3 inches long extending from the head of the first metacarpal to near the middle third of the third metacarpal; a flexor contraction of the middle, ring, and little fingers with deformity of the nails of the ring and little fingers; destruction of the long flexors to the thumb and index finger; complete paralysis of the median nerve except for the motor branch; complete paralysis of the ulnar nerve; and a cicatrix of the dorsal aspect of the first joint of the thumb with paralysis of the extensor.*

*At operation the cicatrix of the palm was excised. Branches of the median and ulnar nerves were located and these nerves were rerouted to gain length. The volar branch of the median nerve was lengthened by blunt dissection. The elbow was flexed and the digital nerves to the thumb, index, middle, and ring fingers (first, second, third, fourth, and fifth branches) sutured. The ulnar nerve was repaired by suturing the motor branch. The distal branch was located between the bellies of the muscles of the flexor and adductor digiti minimi. The three superficial branches were sutured to the respective branches. Extensive nerve repair was necessary because tendon transplantation could not be carried out at this time.*

followed frequently, and continued for periods of 1 to 3 months. By the time the patient reached the Zone of Interior, cicatricial invasion had usually involved the skin, tendons, blood vessels, muscles, nerves, and bones. Malunion and nonunion of bones, with destruction of bones and joints, were present, likewise amputations and deformities, also nerve paralysis. In many instances the patient had completely dissociated his extremity from his brain and refused to use his hand.

The problem was the same at all hand centers: To transform these injured, functionless hands into functional members with normal sensations. Cosmetic results were desirable, but secondary.

## OCCUPATIONAL AND PHYSICAL THERAPY

Before as well as after operation, both occupational and physical therapy played important roles in the treatment of crippled hands. As soon as the patient entered the hand section he was sent to the occupational therapy department where measurements of stiff joints were made and recorded. Occupational therapy was carried out 6 days a week, the routine in general being that recommended by the Civilian Consultant in Hand Surgery (Chapter II, p. 68 ff.).

Physical therapy in the form of heat, light, massage, mild passive motion, and the whirlpool bath was used as indicated. In peripheral nerve lesions the physical therapy department made electric muscle-nerve stimulation tests and recorded the results on special forms.[1]

## SPLINTING

Special types of splints were used in contractures, nerve lesions, ankylosed joints, and as part of preoperative and postoperative therapy. The splints suggested by the Civilian Consultant in Hand Surgery were constructed by orthopedic technicians and modified to meet special situations.

## SPECIAL TECHNIQUES

*Operative Routine.* All operations on the hand were carried out with a pneumatic cuff or sphygmomanometer in place and inflated to 300 mm. of mercury to produce an ischemic field. Acute injuries were not investigated until a tourniquet had been applied and complete preparations for surgery had been made. A wholly sterile technique was regarded as mandatory for even the initial examination.

In general, the operative procedure for reconstructive surgery was as follows: The cicatrix was excised; cicatricial tissue removed from around tendons and bones, and capsulotomy performed as indicated. If nonunion were

[1] Chart for recording progress in testing electrical muscle-nerve reactions of the upper extremity. HD: 730 (Hand Surgery).

the special problem, the ends of the bones were freshened and prepared to receive a graft as a peg, an inlay or an onlay, or as a combination of the latter two. Grafts were secured from the ulna, tibia, or ilium, the ilium being the site of preference. Tendon repair was carried out by suture, transplantation, or tendolysis. A piece of deep fascia was frequently placed between the tendons and the bone graft.

At this point the tourniquet was released and manual pressure applied for 5 minutes. Any bleeding vessels were ligated. Skin edges of the incision were undercut and closure accomplished with No. 36 stainless steel wire. If closure could not be achieved without tension, relaxing incisions were made on the ulnar and radial aspects of the hand. If closure were then still impossible, skin grafts were used. Small grafts, which might be needed to close the relaxing incisions, were obtained from the forearm, using a Ferris Smith knife. Large grafts were removed from other donor areas with a dermatome. Donor areas were closed at once. Unless there were some contraindication the routine postoperative dressing was a palmar and dorsal plaster splint.

*Sterile Dressing Technique.* Great emphasis was placed upon the maintenance of a strictly sterile technique in dressing hands particularly after plastic surgery. So far as possible, the following routine was observed:

1. Under no circumstances was a dressing removed until the dressing cart with full sterile equipment was at the patient's bedside.

2. Dressings were not begun until an hour after floors had been swept and bed linen changed.

3. Windows by each bed were closed before dressings were begun.

4. All ambulatory patients in the ward remained quietly at their bedsides during the routine of dressing.

5. Patients were dressed in order according to a prepared list; noninfected before infected ones.

6. Dresser, assistants, and patients were capped, masked, and dressed in clean gowns.

7. Hands of the dresser and his assistants were scrubbed for 10 minutes with white soap. Nails, which were kept short, were cleaned.

8. One assistant, trained in the aseptic technique of dispensing dressings and medications, dispensed sterile supplies from the dressing cart to the dresser.

9. Bandage scissors were used to cut the outer dressings. These scissors were then placed in a special receptacle for contaminated instruments on the cart.

10. Dressings were removed with sterile forceps or sterile gloves. Contaminated dressings were placed in a container with a lid, never on the floor or the bed; they were never handled by the dispenser of sterile supplies. Contaminated forceps were placed in the container for contaminated instruments. If hands were contaminated in the course of removing the dressings, the tech-

nique of scrubbing for 10 minutes with a sterile brush and white soap was repeated.

11. When the dressings had been removed, a sterile towel was placed beneath and around the hand. A set of sterilized instruments was then opened.

12. If the wounds were clean, medication was applied with applicators or by instrument-held gauze saturated with tincture of merthiolate or some similar solution. The fingers were never placed in or about the wound. Wounds, then the surrounding tissues, were thoroughly painted. Hairs were kept short by shaving the area with a sterile razor.

13. If wounds were infected they were thoroughly cleansed by physiologic salt solution or baths, carried out by a strict routine. Medications such as the sulfonamides, zinc peroxide or azochloramid (chloroazodin [$C_2H_4Cl_2N_6$]) were then applied according to the indications of the special case.

14. Sterile dressings were applied to the wounds at the conclusion of treatment by the knife and fork technique, or after replacing with sterile gloves and instruments the gloves and instruments previously used.

## SPECIAL INJURIES AND SEQUELAE

### Burns

Burned patients received immediately after injury were first given morphine for pain and sufficient plasma to prevent shock. The amount of plasma necessary was estimated by determining the hematocrit level and giving 100 cc. for each point above 45. If hematocrit determination was not immediately possible, the patient was given 500 cc. of plasma for each 10 percent of body surface involved by a deep (blistering) burn. Berkow's [2] method was used to calculate the extent of the burned area. To avoid the pernicious rapid shift of plasma which results in hemoconcentration it was considered essential that plasma be given within the first hour or two after the injury.

Treatment of shock took precedence over all other considerations. When the patient recovered from shock, or immediately if he was not in shock, he was taken to the operating room where examination was conducted under light anesthesia if it could not otherwise be tolerated. Clothing was cut off with scissors. Wounds were carefully examined, dirt and grease removed, and cleansing accomplished with soap and water. Large blebs were punctured and light debridement carried out. Wounds were then covered with fine-mesh gauze and a petrolatum-impregnated pressure dressing applied.

Burned patients were treated with penicillin, sulfadiazine, and sodium bicarbonate and were given a high-caloric, high-protein, high-vitamin diet.

[2] Berkow, S. G.: A method of estimating the extensiveness of lesions (burns and scalds) based on surface area proportions. Arch. Surg. 8: 138–148, 1924.

Patients with burns of the hands usually had burns of other parts of the body and required the systemic therapy described.

Pressure dressings were kept on the wounds for 12 to 14 days. Skin grafting was carried out promptly if it seemed necessary when the burns were inspected at this time. Early skin coverage and early motion in the small joints were strongly emphasized.

When cicatrices of the hand, wrist, and forearm resulting from burns were ready to be removed and grafts applied, the tourniquet was placed and the entire cicatrix covering the wrist or the dorsum of the hand excised. Capsulotomies were performed and skin edges undercut to permit them to retract. All skin which possessed normal sensation was spared. After the cicatrix had been removed the tourniquet was released and manual pressure applied for 5 minutes. Spurting vessels were clamped and ligated with No. 3–0 plain catgut. The tourniquet was then reapplied and the entire area grafted with a sheet of skin usually obtained with a dermatome. The skin was sutured with a continuous suture of No. 3–0 black silk or with No. 40 stainless steel wire. When skin grafting was carried out near, but not in, flexor creases and webs, points of the graft were carefully extended beyond the creases since a suture line in such a location usually causes contractures. Following the operation, fine-mesh gauze was placed over the graft, then a thick layer of wet absorbent cotton or a large amount of mechanic's waste. The hand was immobilized in the position of function and pressure bandages applied. Finally, the tourniquet was removed.

## Osteomyelitis

Osteomyelitic lesions were saucerized. If the areas were small, skin grafts were applied immediately, but if large, they were withheld for 7 to 10 days. This plan of treatment proved of great value and in many instances permitted the salvage of lengths of fingers and of other bones, such as a metacarpal, to maintain the breadth of the palm.

## Fractures

Malunited and ununited fractures, observed in large numbers, were treated by osteotomies and bone grafts (Figs. 110–115) from the ulna, tibia, and ilium. The choice of procedure and the special technique depended upon the needs of the special case.

The few acute fractures of the bones of the hand which were observed on the hand service were treated by standard methods, including plaster of paris splints and mechanical splints. Fixation with Kirschner wires was used as necessary.




*Figure 110. Worksheet for patient with injury of left hand caused by hand grenade (Fig. 111). When this soldier was admitted he had compound comminuted fractures with nonunion (or minimal union) of the third, fourth, and fifth metacarpals and loss of extensors of the third, fourth, and fifth fingers. He also had a cicatrix and an extensor contraction of the second finger.*

## Ankylosis and Contractures

Since each case had to be planned individually it would be impossible to describe, or even to list the various procedures employed in the correction of deformities of the hand (Figs. 111–118). In one case arthroplasty might be employed, while in another the patient might be better served by arthrodesis, and in yet another by bone graft. A flexion contracture might be corrected by a pedicle graft. The list of possible procedures and combinations of procedures was endless, but the principle of management was always the same: To adapt the procedure to the patient's needs and not to set up rigid procedural outlines into which cases were fitted. When that principle was carefully adhered to, good results, were achieved in the majority of cases often in the face of serious deformities.

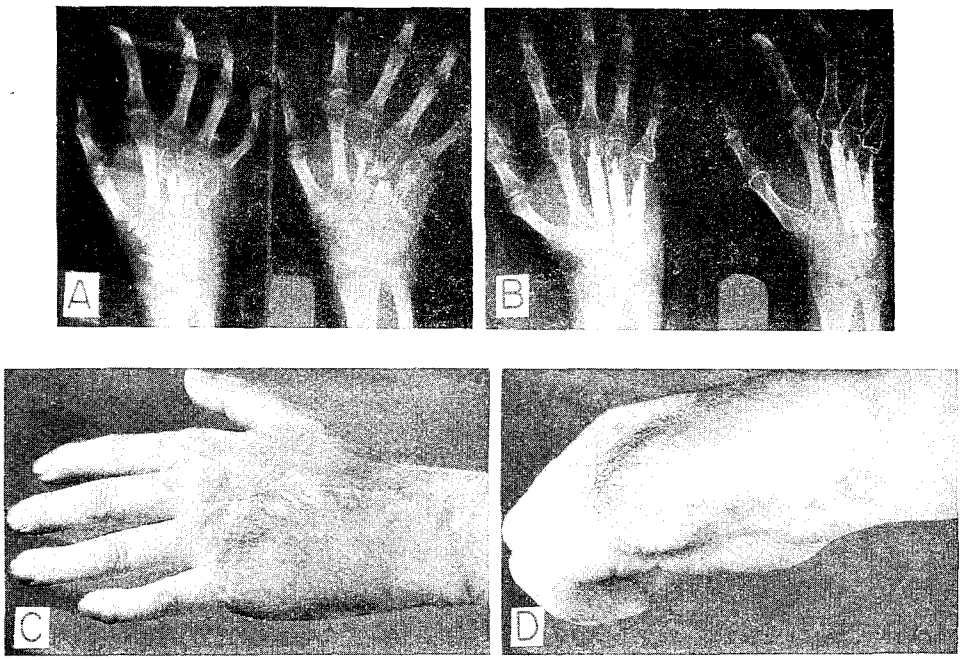



*Figure 111. A. Preoperative, and B, postoperative roentgenograms in hand injury shown on worksheet in Figure 110. C and D. Clinical end results. After skeletal traction had been applied for 26 days in this case, the fractured metacarpals were repaired by bone grafts. Later the pedicle flap which had been applied overseas was defatted and new extensor tendons to the third, fourth, and fifth fingers grafted from extensor tendons of the toes. Functional results were excellent.*

## Nerve Lesions

According to the exigencies of the special case nerve lesions were repaired by neurolysis, suture, transplantation, and transfer. More than 150 nerves were sutured and about 35 nerve transplantations carried out. Gaps of as much as 5 inches in the median and ulnar nerves were overcome by rerouting the nerve and flexing the hand, wrist, elbow, and shoulder as necessary. In 1 patient, 4 nerve transplantations were effected in the palm of the hand. In another, a gap of about 7.5 inches between the proximal and distal branches of the ulnar and median nerves was shortened by placing a wire in each of the neuromas for traction in the forearm. The distal end of the wire was carried out through the palm, where continuous traction was accomplished by rubber bands.

Nerve injuries were immobilized for 4 weeks in plaster of paris which was then replaced with a mechanical splint fitted with an external bar that permitted extension every 3 days.

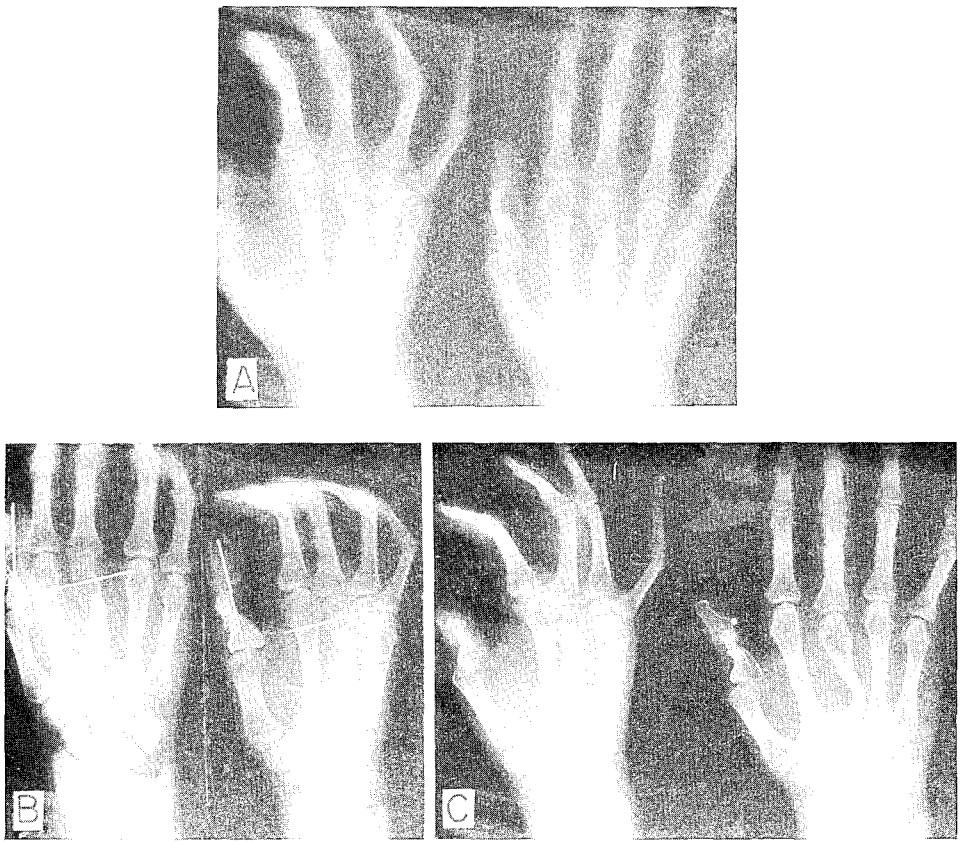



*Figure 112. Injury to right hand from shell fragment with malunion of third metacarpal and of first phalanx of thumb, flexor contraction and median nerve paralysis. A. Preoperative roentgenogram. B and C. Serial postoperative roentgenograms following correction of malunion of third metacarpal by bone graft and arthrodesis of distal joint of thumb.*

## Amputations

The following were indications for amputation:

1. Acute traumatic hand injuries in which a severe compound fracture involved a joint, the surrounding soft tissues were macerated, irreparable damage had occurred, and it was evident that the affected portion of the hand or finger could serve no useful purpose if left in situ.

2. Involvement of two or more structures to such a degree that the surgeon could predict with certainty that the digit or other portion of the hand would be functionless. An illustration of this type of injury would be complete severance of the principle digital arteries, nerves, and bone, with no evidence of blood supply in the distal structures.

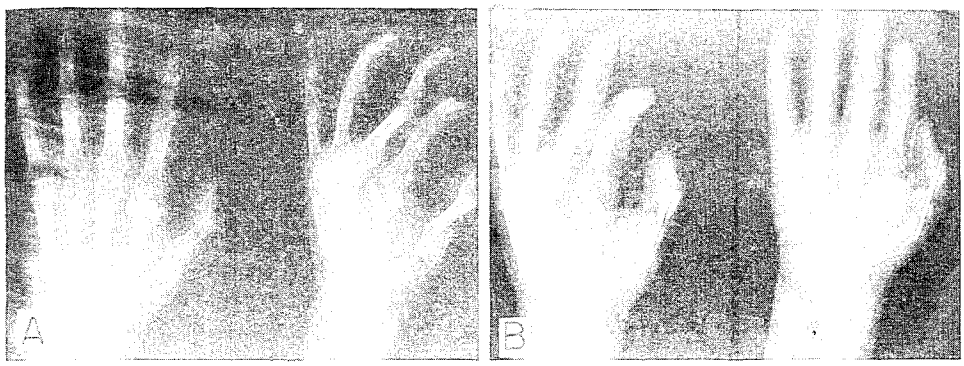



*Figure 113. Injury of left hand from shell fragment, with malunion and ankylosis of proximal joint of thumb and malunion of head of second metacarpal. A. Preoperative roentgenograms. B. Postoperative roentgenograms after application of bone graft to thumb and pin fixation.*

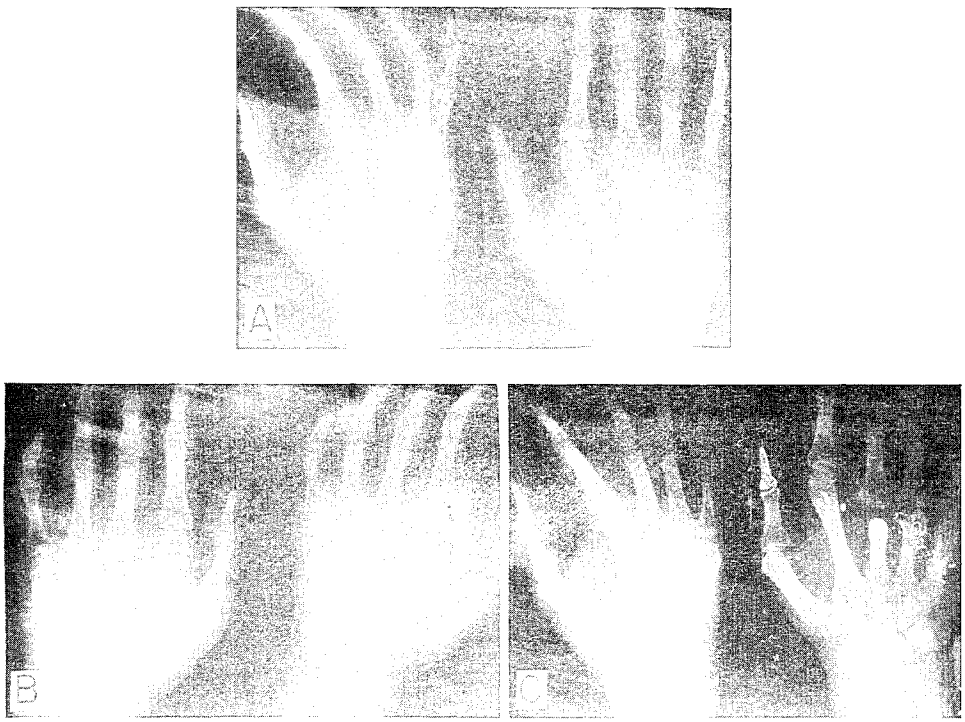



*Figure 114. Injury of right hand from machinegun fire with compound comminuted fractures of third, fourth, and fifth metacarpals. A. Preoperative roentgenogram. Note malunion, angulation, and ankylosis of proximal joints and multiple foreign bodies. B and C. Postoperative roentgenograms following osteotomy and bone graft of fourth and fifth metacarpals and arthroplasty of proximal joint of third finger. Functional results were excellent.*




*Figure 115. Injury of right hand from shrapnel with malunion and nonunion of fractures of ring and little fingers, resulting in limitation of motion and loss of flexion. A. Preoperative roentgenogram. B and C. Postoperative roentgenograms after correction of bony deformities by bone grafts. Functional results, excellent.*

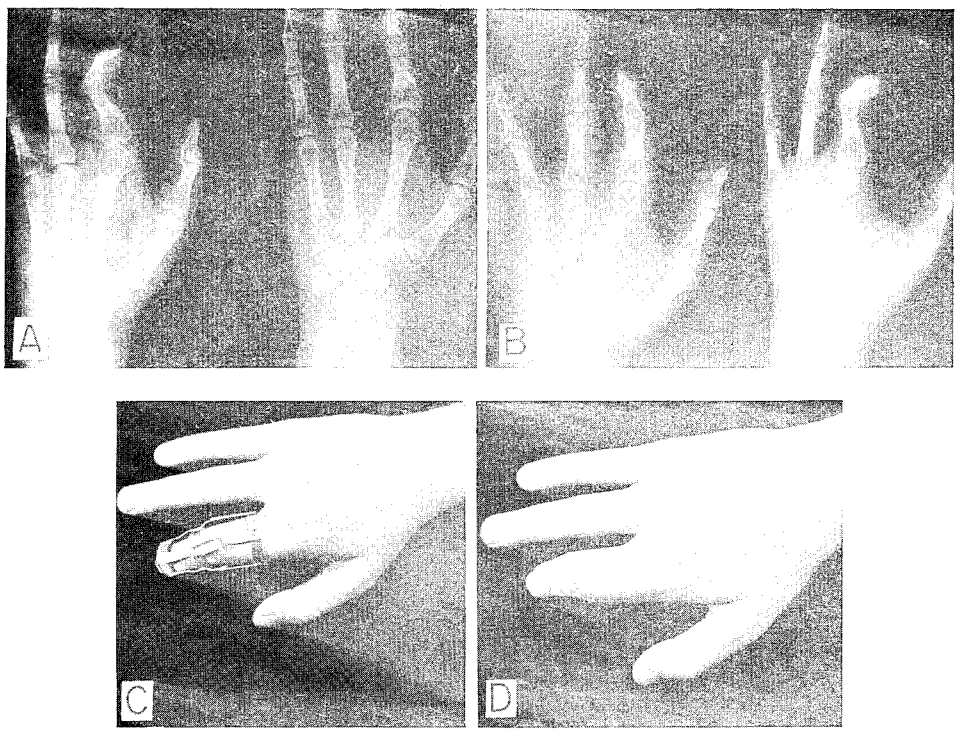



*Figure 116. Injury to left hand by shell fragment; amputation of middle finger and third metacarpal; compound comminuted fracture of proximal phalanx of index finger with malunion and ankylosis of proximal and distal joints. A. Preoperative roentgenogram. B. Postoperative roentgenogram after transplantation of index finger, bone graft and capsulotomy of proximal joint of index finger. C and D. Clinical results. In C note use of finger splint to correct flexion deformity of middle joint of index finger.*

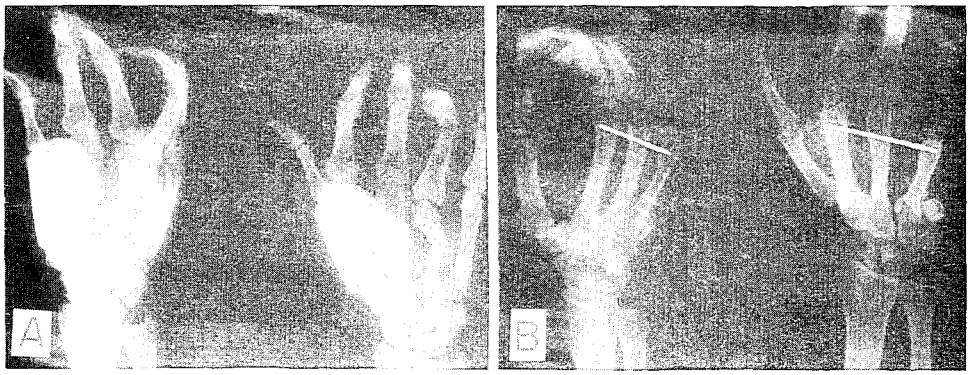


*Figure 117. Bony injury of right hand from accidental discharge of machine gun; cicatricial contracture of flexor and extensor tendons. A. Preoperative roentgenograms. B. Postoperative roentgenogram following excision of fourth metacarpal and transposition of fifth into its place.*

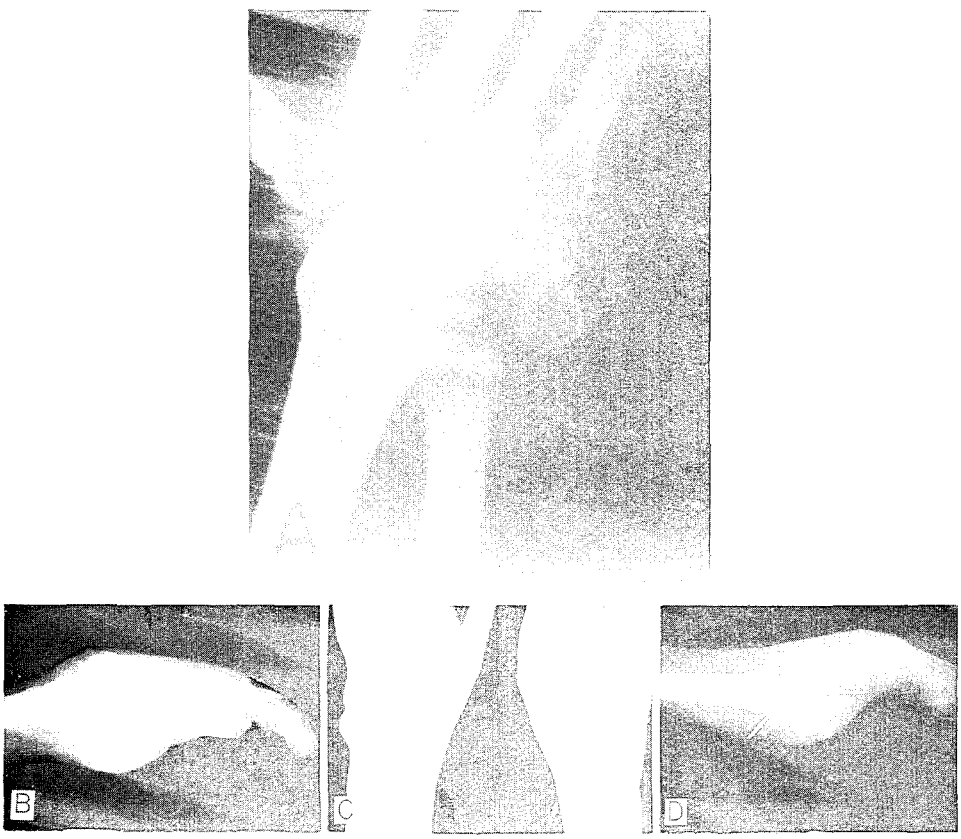


*Figure 118. Multiple damage to right hand following land mine explosion. A and B. Preoperative roentgenograms. C and D. Postoperative roentgenograms following excision of head of ulna and arthrodesis of wrist.*

3. Infection in which the end result was loss of function to the portion of the hand or fingers affected. This indication was entirely theoretical. In the hand service at Crile General Hospital there were no instances of uncontrolled infections of hematogenous origin or of wound contamination by *Clostridium welchii.*

4. Malignant tumors, none of which were seen. Benign tumors of the hand were observed, but none were so located as to destroy function.

5. Deformities of the hand of such a character that function of remaining portion would be improved by amputation of the badly injured part. An illustration would be flexed, ankylosed long finger, with vascular and nerve injuries and irreparable destruction of bone and tendon.

After amputation, whether traumatic or surgical, various procedures were used (Figs. 116, 119, and 120). The length of a stump was often increased by tube pedicles and bone grafts. The chief problem was to save as much of the stump as possible. In many instances, instead of revision by reamputation, a tube pedicle was applied. At other times a flap of good skin from the dorsum was used to cover the stump; this procedure supplied desirable normal sensation. The donor area was grafted.

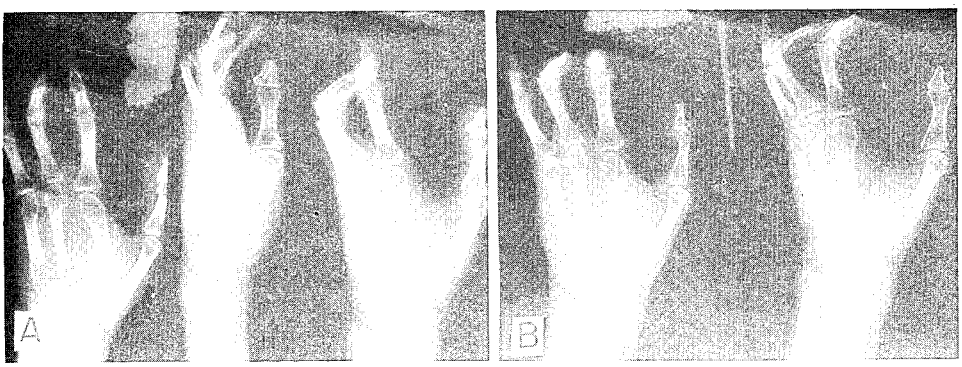



*Figure 119. Injury of left hand from bullet with amputation of third finger and corresponding metacarpal. A. Preoperative roentgenograms. B. Postoperative roentgenograms after transplantation of index metacarpal to replace third metacarpal, and iliac bone graft.*

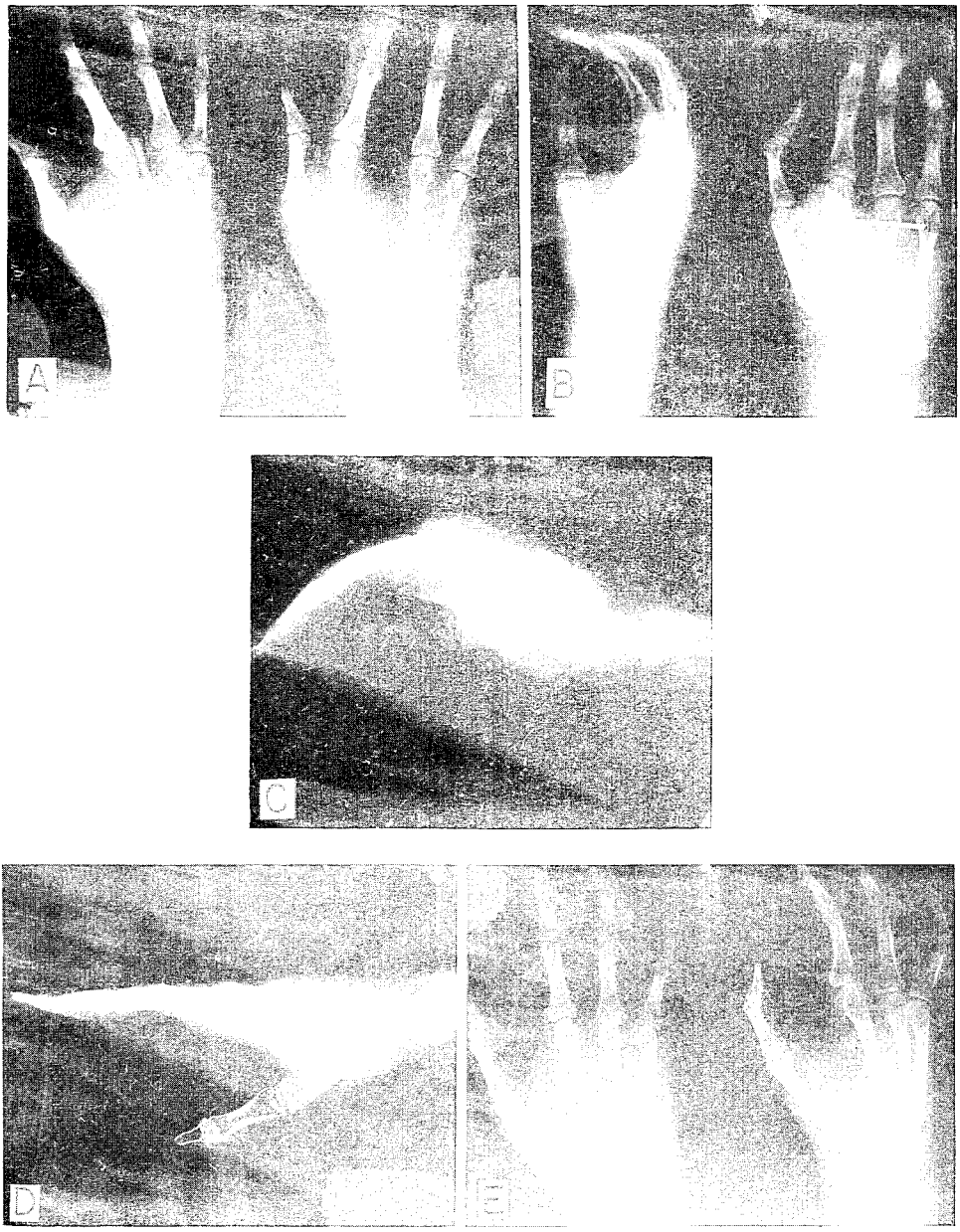



*Figure 120. Machinegun injury of right hand with amputation of middle finger and its metacarpal, median nerve paralysis, and cicatricial deformity of palm. A. Preoperative roentgenogram. B and C. Postoperative roentgenograms following transposition of second metacarpal into place of third. D and E. Roentgenograms showing final functional results: Metacarpal has normal alinement, pointing of finger is normal, and proximal joints have normal range of motion.*

CHAPTER IX

# Hand Surgery at Cushing General Hospital

*J. William Littler, M. D.**

## GENERAL RECONSTRUCTION PROBLEMS

Although many patients received at Cushing General Hospital with hand injuries during the course of World War II showed secondary healing on admittance, the skin covering was frequently inadequate for the work of reconstruction. Among those who required bone grafting, approximately 17 percent first required skin replacement by means of abdominal pedicle flaps. In another large group, scars had to be excised before healthy skin edges could be approximated.

Another important problem preliminary to reconstruction was mobilization of the hand which had become stiffened secondary to joint and tendon fixation. The metacarpophalangeal joints were the most obstinate, especially when the dorsum of the hand and the extensor tendons had been extensively damaged. When the tendons had become bound in scar tissue and to metacarpal fractures, the metacarpophalangeal joints were hyperextended and the collateral ligaments contracted. The cycle could be broken only by extensive surgical release of the extensor tendons and complete excision of the collateral ligaments followed by elastic spring splinting with the wrist in extension, and early active exercise.

In the program of reconstruction both elastic spring corrective splinting and physical therapy were used extensively. Surgical procedures to get the hand into the best possible position were promptly employed. Excision of cicatrices, joint fusion, tenotomy, capsulectomy, and plastic procedures were all employed to hasten restoration of function.

Metacarpal fractures were common, but difficult to manage only when the head and the metacarpophalangeal joint had been destroyed. An injury of this kind usually meant the loss of the digit or the development of a pseudoarthrosis. Although the fourth or fifth metatarsal, with its head, can be used as a transplant in such cases, this procedure was not employed at Cushing General Hospital. In selected cases a graft which fused the joint at 30 degrees was used. A functionless digit was removed. If the third or fourth metacarpal head was destroyed the entire metacarpal was removed and either the base of the second or fifth metacarpal shifted, or the proximal phalanx of the involved ray recessed, to fill the metacarpal defect.

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*Consultant in Surgery, Valley Forge Army Hospital. Formerly Major, MC, AUS.

Careful fitting of bone grafts using tibial bone eliminated the need for fixation by Kirschner wire in most cases, though many uses for this method were found in restoration of the architecture of the hand.

No attempt was made to immobilize fractured metacarpals when there existed extensive loss of bone substance. Instead, attention was directed toward preservation and development of residual function. Many patients had shortened fingers and thumbs secondary to metacarpal and phalangeal fractures, but no attempt was made to restore length by skeletal traction. Satisfactory length could be gained only by bone grafting to bridge the defect, after careful and complete excision of the scar tissue between the metacarpal fragments.

Osteomyelitis was not a serious problem. When present, the carpus and metacarpals were chiefly involved. Treatment consisted of sequestrectomy, followed by the use of dressings saturated with penicillin solution. Later, after healing, skin replacement was carried out by pedicle flap or scar excision if reconstructive work had to be done. Persistent osteomyelitis of the hand was most unusual.

Had the position of function and attention to proper instruction of the patients in active and passive mobilization of the injured hand been appreciated more often by the general surgeons responsible for the management of battle casualties, many more hands would have been ready for reconstructive procedures soon after the arrival of the patients in the Zone of Interior. This was particularly true of longstanding nerve injuries, in which three deformities were commonly seen: (1) Adduction contracture of the thumb, present in median nerve loss; (2) stiff, hyperextended metacarpophalangeal joints, present in radial and ulnar nerve loss (had only the wrist and not the proximal phalanges been supported in radial nerve injuries, there would have been fewer stiff metacarpophalangeal joints); and (3) flexion contractures of the interphalangeal joints of the fourth and fifth digits, present in ulnar nerve loss. When vascular injuries and injuries of the median and ulnar nerve were associated, Volkmann-like contractures of the wrist and fingers frequently resulted.

When the metacarpophalangeal joints were fixed in extension secondary to a nerve injury, excision of the collateral ligaments often gave excellent results. If nerve regeneration had not progressed to the point at which voluntary flextion of the fingers was possible, the hand was maintained in the position of function and persistent passive exercise carried out.

In appropriate cases inoperable nerve injuries could be managed by tendon grafts and transfers. When for instance the recurrent motor branch of the median nerve was found to be irreparably damaged, a tendon transfer for the restoration of opposition could usually be done if the thumb had been properly mobilized through its functional range.

Tendon transfer, which was a satisfactory method of treatment in radial nerve paralysis, was not carried out if the metacarpophalangeal joints were stiff or the area of transfer anesthetic. An occasional patient was received who

had been submitted to nerve suture at the wrist or within the carpal tunnel but whose associated tendon injuries had not been repaired. This was always unfortunate. Invasion of the hand for several separate surgical procedures which might have been combined invariably meant increased scarring, and almost always resulted in decrease of function.

Hands which reflected the results of vascular injuries were benefited by sympathectomy. Improvement in the blood supply brought about relief of pain, while at the same time motion was improved and reconstructive surgery simplified and given a better chance of success.

Fingers damaged beyond the scope of reconstructive surgery were removed, this procedure greatly enhancing the function of the remainder of the hand.

Total loss of the thumb was seen in a few cases only. In certain of these, all carefully selected, transposition of the adjacent finger proved a worthwhile procedure. A number of badly damaged thumbs were greatly improved by bone grafting followed by such nerve and tendon repairs as were indicated.

Not many patients had to be sent to amputation centers. Such cases were usually carefully screened originally and did not find their way to the hand centers.

Emphasis was always placed upon the performance of reconstructive surgery in the proper sequence. The early considerations were mobilization of the stiffened hand, provision of good integument, and restoration of sensation. Then followed bone and joint repairs, further mobilization, and finally nerve and tendon repairs. Tendon repairs were not attempted until a good range of joint function had been obtained, and tendon grafts were never placed in anesthetic fingers.

## CORRECTIVE AND PROTECTIVE SPLINTING

Deformities of injured hands were common. Omission of splinting and improper splinting were very frequent causes.

Corrective splinting was seldom necessary in hands on which protective splinting had been employed and for which persistent active and passive exercise had been undertaken. These practices maintained opposition of the thumb, metacarpophalangeal flexion, wrist extension, and similar favorable factors until nerve regeneration occurred or until appropriate tendon transfers and grafts could be performed. Appropriate protective splinting lessened functional disability and avoided the necessity for weeks of corrective splinting. At Cushing General Hospital hands were not immobilized in the absence of indications; when they existed, the optimum position of function was maintained.

A frequent cause of residual stiffness of the hand arose from the gross edema which is likely to follow all injuries as soon as they have occurred. Unless the hand was kept constantly elevated, stiffness was inevitable. It would

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have been a simple matter to immobilize only the injured parts and permit the remainder of the hand to be exercised, but in many instances this was not done and the entire hand, up to and sometimes including the fingers, was splinted.

Adduction contracture of the thumb was a common finding in hand injuries associated with peripheral nerve injuries. Until the deformity was corrected and the proper position maintained, function could not be restored in such cases. Elastic spring splinting, started promptly, would have prevented this sort of deformity. When the deformity had been permitted to become established, mobilization of the metacarpal joint by traction was not always successful and surgical intervention became necessary.

## SKIN REPLACEMENT IN MISSILE WOUNDS

All patients with missile wounds of the hand seen at Cushing General Hospital were presented at one of the periodic hand conferences, where the question of skin replacement was discussed. If sequestration were still occurring, the plastic procedure was deferred. Meantime, the patient was referred to the osteomyelitis ward where devitalized bone and foreign bodies were removed. Then when the sinuses had healed, decision concerning replacement of skin was made.

Early in the operation of the hand center there was developed a policy of recommending skin replacement whenever there was doubt as to whether this was or was not necessary. As time passed, the opinion that this was the proper procedure in all questionable cases was strengthened.

In some cases it was a simple matter to replace dorsal scars by advancing a skin flap from the proximal margin of the defect. This maneuver was occasionally combined with some form of rotation or with a Z-plastic flap. In the majority of cases, however, more tissue than could be obtained locally was required. The usual procedure was to utilize a direct abdominal pedicle flap, based superiorly or inferiorly according to the particular need. As time passed, primary transfers were increasingly employed. In the occasional case in which a bulky flap was desired, dissection was carried down to the deep fascia. More often the flap was thinned considerably at the time of application. The defect in the abdominal wall from which the flap had been secured could often be completely closed by mobilization of adjacent tissue. If it was too large to be repaired in this manner it was narrowed by mobilization of adjacent tissue and suture of skin margins to the fascia, then covered with a thick split graft.

The area about the flap was carefully packed with fluffed gauze over which a smooth layer of surgical waste was applied. The arm was then immobilized with adhesive strapping or with a light plaster jacket. For the first week after operation penicillin was given by the intramuscular route. The original

dressing was left undisturbed for 2 weeks. Sutures were removed at that time and the area dressed daily until time of detachment.

During the first few months after the reconstructive hand surgery program was instituted at the Cushing General Hospital, flaps were set in directly at the time of detachment. When several significant losses occurred under this plan, delayed procedures were employed unless the margins to be set in were very narrow. In all other cases the pedicle was detached in one or two stages and was allowed to granulate for an average of 5 days. During this period moist dressings or vaseline-impregnated gauze dressings were used and powdered sulfadiazine applied. Penicillin was given routinely for 36 hours before the flap was inserted and for 6 days afterward. Under this regimen the incidence of marginal loss of the grafted flaps decreased markedly.

Small defects about the web spaces at the base of the digits were repaired with direct pedicle flaps from the groin or from the opposite arm. Although the skin of the medial aspect of the upper arm was somewhat thinner than the skin of the abdomen, the technical difficulties of operation in this area were greater and the lower right quadrant was usually used as the site of preference.

Tubed pedicle flaps were used occasionally, particularly for defects on the volar surface of the hand or for combined defects in the thenar region. They were usually secured from the thoraco-epigastric region, applied and set in by the usual technique, generally with good results. The one-stage single pedicle abdominal tube also proved very effective in resurfacing the hand, particularly in reconstruction of a contracted thenar area.

In the course of skin-replacement operations it was the usual practice to excise scar tissue, identify intact tendons and tendon stumps, and observe and record nerve damage. It was not the usual practice to reconstruct the deeper structures at this time. One procedure, however, was adopted early in the program and utilized whenever possible throughout the operation of the center: When tendons which were intact had been freed from encasing scar the fatty portion of the abdominal pedicle flap was split and a thin, fatty sheet carried beneath them before it was resutured in its normal position. Protection of the freed tendons with this fatty sheath frequently resulted in the prompt restoration of function.

In a number of patients the median or ulnar nerves in the wrist and proximal portion of the hand were sutured when the abdominal pedicle flap was applied. The combined operation was not employed, however, unless the suture line of the nerve lay well within a safe portion of the flap and could be encased in fat.

## BURNS

Burns of the hand were usually healed by the time the patients were admitted to Cushing General Hospital. The chief problems in burn injuries concerned the release of contractures and replacement of unstable scar tissue.

In most burns there was no doubt when the patient was first seen that partial or complete replacement of the skin of the dorsum and digits would be necessary. When there was uncertainty as to the need for this it was the policy to grant work furloughs for periods of 4 to 12 weeks, following which decision on replacement was seldom difficult.

Whenever feasible, the fingers and dorsal surface were grafted at the same time. When a two-stage procedure was necessary the first replacement included the hand and the metacarpophalangeal joints, and the second, the fingers.

In general, the technique was as follows: With a tourniquet in situ the scar was excised, after which pressure was released and hemostasis obtained. Thick split grafts taken with a dermatome were affixed to the recipient area with continuous sutures, and without perforations of the graft except in obviously vulnerable areas. Grafts were always placed with their borders on the midlateral aspect of the digits and parallel to the flexion creases. In some cases the tourniquet was replaced before the graft was applied and the wound dressed, in others it was not.

At the conclusion of the operation uniform pressure was obtained by the use of surgical waste applied over a single layer of vaseline-impregnated gauze and fluff dressing. The thumb was placed in the position of abduction and the other fingers in semiflexion. The first dressing was usually deferred until the eighth day after operation. The wound was then dressed every day or two until healing was complete.

The results of grafting were practically always good. Occasionally small areas which did not take were regarded as significant enough to require resurfacing with Thiersch grafts. In a number of patients recurrent contracting bands, most of which appeared in the web between the thumb and index finger, also required regrafting. After adoption of the policy of creating a sharply broken line along the web when the initial grafting was done, the number became insignificant.

## BONES AND JOINTS

### Bone Grafts

During the early period of its operation the activities of the orthopedic section of the hand surgery division were devoted chiefly to bone and joint reconstruction. Following the necessary skin replacement, efforts were directed toward developing and maintaining a functional position in the joints and the elimination of irreparably damaged digits which impeded return of function. Stabilization of the fractured metacarpal bones by bone graft, corrective osteotomy, joint fusion and arthroplasty, formed the framework upon which good function depended. Pain at the site of a fracture could also be relieved by a bone graft.

In 5 patients small bone grafts were used to bridge defects in the phalanges of the thumb. These were chiefly instances in which the proximal phalanx and the interphalangeal joints had been completely disrupted.

Metacarpal grafting was carried out in 45 patients, in whom 57 individual grafts were applied. Individual grafts were used for each metacarpal, and sometimes as many as 3 were applied at a single operation. In all but 2 patients union was evident during the third month after operation. In 1 of the failures a small graft became absorbed and in the other the graft failed to unite with a small, atrophic (third) metacarpal head which angulated volarwardly.

In destructive metacarpal fractures with loss of bone substance, grafting proved a worthwhile procedure in restoring the architecture and strength of the hand. Following a destructive metacarpal fracture metacarpophalangeal function was invariably lost or impaired. In this type of case the joint was pulled into extension, and flexion was chiefly gained at the site of the fracture Only by stabilization of the metacarpal head with a bone graft could joint function be restored. Collateral ligaments could be excised either when the graft was applied or after union had occurred. When function of the flexor tendon was present, its effectiveness could be greatly increased by stabilization of the ray (metacarpal and digit).

The basic principles which apply to grafts of larger bones were for the most part applicable to grafts of the metacarpals. In general, success of bone grafts was in direct relationship to the accuracy with which the graft was fitted into the recipient metacarpal fragments. Because of the small size of the affected bone, however, fixation by plates and screws was usually impractical and this disadvantage had to be compensated for by more attention to the finer details of what Dr. Sterling Bunnell has called bone carpentry (see Chapter II, p. 44). If additional fixation were desired, it could be obtained by the use of Kirschner wires which could be transfixed into adjacent uninvolved metacarpals. When only the head and a portion of the neck of the metacarpal remained, stabilization could be accomplished by extending a bone graft into the appropriate distal carpal bone. When multiple metacarpal defects were present, multiple bone grafting could usually be performed in a single operation (Fig. 121).

The shortened finger, with a stiff, hyperextended metacarpophalangeal joint, which so frequently complicated long standing, badly comminuted metacarpal fractures, required preliminary stabilization of the metacarpal with a bone graft if restoration of useful function was to be accomplished. When joint stiffness persisted in spite of bone grafts and intensive physical therapy, excision of the collateral ligaments and lysis of the extensor tendons was often necessary.

Disability resulting from nonunion of the metacarpal of the thumb was much greater than that following a similar condition in other metacarpals. If the proximal portion of this metacarpal had been damaged, the carpometacarpal joint was fused. If the thumb could be placed and maintained in good

position, a useful digit usually resulted (Fig. 122). If the injury involved the distal portion of the first metacarpal with extension into the metacarpophalangeal joint, fusion of this joint at approximately 30 degrees of flexion was usually the best procedure.

*Technical Considerations.* The use of a pneumatic tourniquet greatly simplified the application of bone grafts. The upper end of the tibia was usually preferred as the source of the graft, both because it is stronger than the ilium, which was sometimes used, and because it can be shaped more readily. Bone sufficient to graft all the metacarpals to be repaired at the same operation could be taken at one time from the source selected. The defect between the

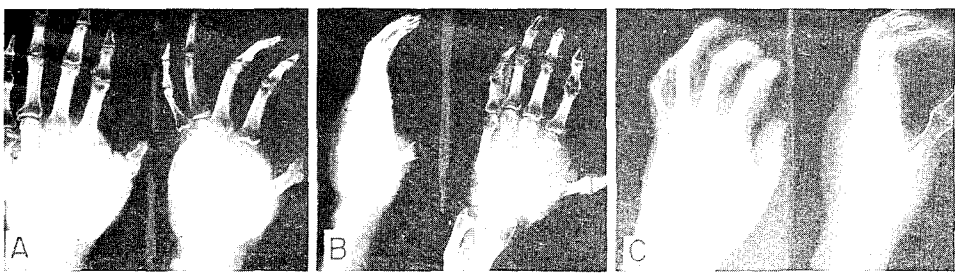



*Figure 121. Correction of massive defects of first, second, and third metacarpals. A. Roentgenograms showing extent of damage. B. Postoperative roentgenograms showing restoration of second and third metacarpals by replaced doweled tibial grafts. Note proximal ends of grafts embedded into the corresponding carpal bones. A bone graft to the first metacarpal is still needed. C. Replacement graft for first metacarpal in situ. The ring finger can now be opposed to the index finger.*

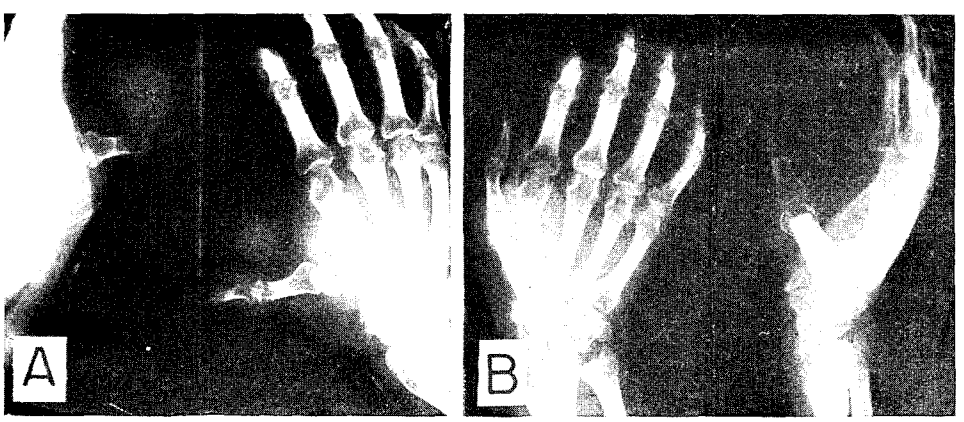



*Figure 122. Correction of massive defect of metacarpal of thumb. A. Roentgenograms showing extent of defect; note that only the head of the metacarpal remains in situ. B. Postoperative roentgenograms showing bone graft inserted in carpal fragment and adjacent metacarpal base.*

metacarpal fragments was accurately measured and the graft from the tibia (or less often the ilium) was cut ½ inch longer than the estimated defect. A dowel was fashioned on one end by means of the circular saw (Fig. 123).

Exposure of the damaged metacarpal was accomplished through a longitudinal or a curved incision, depending upon the presence of scar tissue and the nature of the resurfaced defect. Tendons were freed of all scar tissue, care being taken to preserve the paratenon intact. Fibrous tissue between the metacarpal fragments was dissected en bloc until a bed of soft normal tissue was exposed. The periosteal sleeve was carefully elevated from the metacarpal fragments, the ends of which were accurately shaped to receive the graft. In most cases the proximal fragment was sacrificed to its base, where it was undercut with the osteotome at an angle of approximately 15 degrees. The distal fragment was cut transversely with the circular saw or with rongeurs,

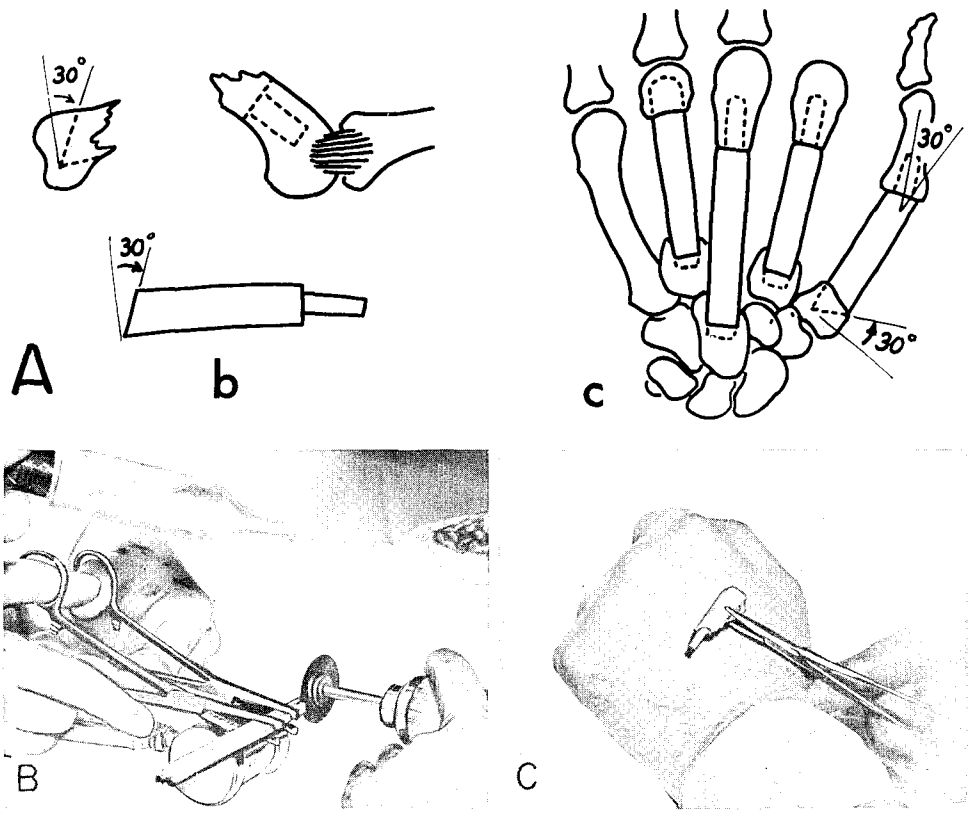



*Figure 123. Repair of metacarpal fracture. A, a. Typical destructive metacarpal fracture, b. Shaped bone graft from tibia, and c. Types of metacarpal grafting. B. Shaping of tibial graft, after removal, with circular saw. C. Dowel for intermedullary fixation of tibial graft.*

and the medullary canal was prepared to receive the doweled end of the graft. When the scar tissue had been resected, it was usually possible to regain by traction some of the lost finger length.

Tension between the two fragments was usually great enough to hold the graft in place at the base, but in a small number of cases fine stainless steel or Kirschner wires were employed for additional fixation. The periosteal sleeve, if it were present, and the soft tissues were closed over the graft with fine silk. At the conclusion of the operation a plaster of paris cast was applied with the hand in the position of function and was extended just distal to the proximal interphalangeal joints. To facilitate postoperative decompression it was split as soon as applied. On or about the 12th day after operation it was replaced by a new cast which immobilized only the grafted metacarpal. Good union ordinarily occurred within 6 to 12 weeks.

Although persistent osteomyelitis of the bones of the hand was extremely uncommon at Cushing General Hospital, prophylactic measures were carried out before and after surgery. When penicillin became available it was given routinely for 48 hours before all hand operations and continued for 8 days or longer after operation. This precaution was considered necessary because all of these injuries were compound fractures and either potentially infected or had previously been complicated by osteomyelitis.

## Capsulectomy

A hyperextended metacarpophalangeal joint sometimes yielded under the pressure of proper splinting (Fig. 124) but the results of attempted flexion by this method were generally poor and surgical intervention was found to be the quickest and most effective method of accomplishing the desired results.

Two important types of deformity were observed following prolonged hyperextension of the metacarpophalangeal joints:

1. Shortening of the collateral ligaments in the absence of tendon injuries. In this type of case flexion could usually be accomplished by simple excision of the affected collateral ligaments. After the phalanx had been flexed, the volar cul-de-sac of the joint was developed by pressing the articular surface of the phalanx well beneath the metacarpal head, care being taken not to subluxate the phalanx. After operation, the wrist was held in extension, and the proximal phalanges in 90-degree flexion, for 10 to 12 days. Elastic traction was then applied and active and passive motion begun. An important consideration, especially in the presence of ulnar motor nerve loss with intrinsic muscle paralysis, was the preservation of the collateral ligaments on the radial aspect of the second and fifth metacarpophalangeal joints because of the loss, primarily, of the first dorsal interosseus muscle. The preservation of these two ligaments helped to preserve impaired joint stability and thus prevented greater accentuation of the ulnar deviation.

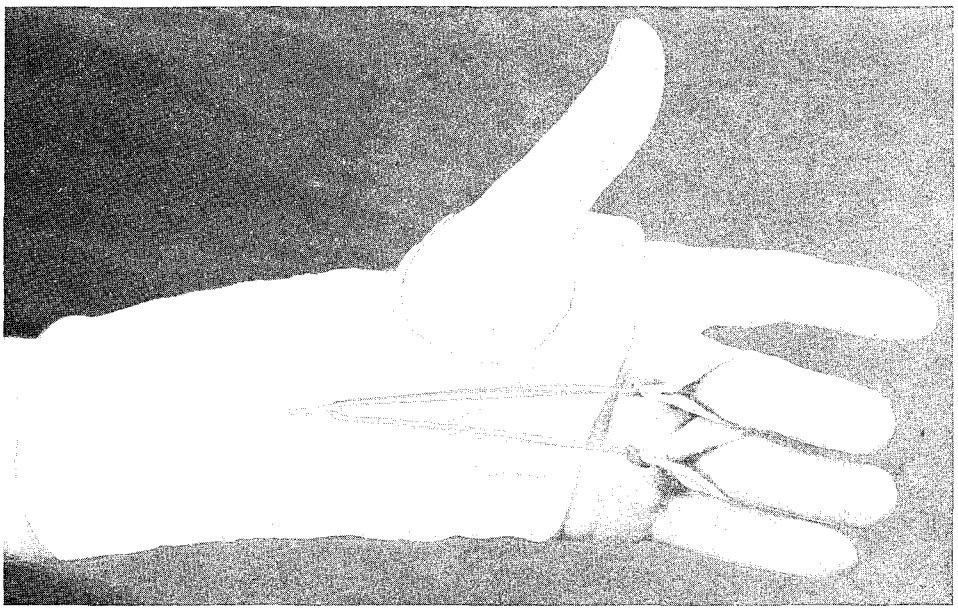


*Figure 124. Traction splint designed to flex the metacarpophalangeal joints in contracture of the collateral ligaments.*

2. The second type is that wherein the joint is complicated by bone and tendon damage. In such cases capsulectomy will not suffice and resort must be had to arthroplasty.

## NERVE REPAIR

Nerve injuries in the wrist and hand were cared for on the hand service but it was the custom at the Cushing General Hospital for the neurosurgical service to handle all nerve injuries above the wrist. When tendon injuries were associated, as they frequently were, it was usually possible to combine their repair with that of the damaged nerves.

When the recurrent branch of the median nerve was found to be irreparably damaged, the opponens loss could usually be compensated for by tendon transfer. When, as often happened, the injury involved the median nerve in the region of its branching, it was of the utmost importance to identify, and to dissect carefully, the individual branches to the thumb and index finger and the two common volar nerves. An injury in this location seldom left the recurrent motor branch intact, or even in a state in which suture was feasible. The maintenance (or restoration) of sensation was the first consideration of repair, especially sensation to the thumb and index finger. To this end the palmar branches were carefully grouped and sutured to the proximal stump of the median nerve. Proximal injuries required careful end-to-end approximation,

with proper bundle alinement, which was accomplished, if necessary, by mobilization of the nerve trunk combined with joint flexion.

If the gap were not too great the palmar nerves were easily sutured following excision of the neuroma and scar. If the ends could not be approximated, and if an important sensory loss had occurred, short nerve grafts were used, taken either from a functionless digit or from the crural nerve. Nerve transfer was possible if an amputated finger were available (Fig. 125). In a number of cases in which suture of the palmar nerves had been carried out, the patients remained at the hospital long enough for return of sensation to the previously anesthetic areas to be observed.

Suturing proved such a simple and satisfactory procedure that there was no experience with the plasma glue method of approximating small nerves. In two patients in whom small nerve grafts had been done they remained under observation long enough for an evaluation of results. In one instance sensation returned to the terminal phalanx of the finger in 5 months and in the other in 7 months.

A simple method of testing eliminated overlap and assured that nerve regeneration had occurred through grafts: Point stimulation from sensory overlap could be localized accurately by the patient, but point stimulation in an area which had been reinnervated would be referred to other areas. (If the fingertip was stimulated, sensation might be localized by the patient at the base of the finger.)

In one patient in whom a transposed digit was partially anesthetic and the superficial branch of the radial nerve was sutured to the lateral index digital nerve (Fig. 126) at a second operation, a return of sensation was present on the lateral aspect of the transposed digit at the end of 4 months.

When the motor branch of the ulnar nerve was implicated in injuries of the hand, palsy of the intrinsic musculature occurred radial to the point of injury. It was not found possible to suture this branch in any case observed at the Cushing General Hospital. Disability resulting from loss of the first dorsal interosseous muscle associated with ulnar deviation of the index finger was corrected by tendon transfer.

## TENDON REPLACEMENT

Loss of tendon function either because of local damage or as the result of motor nerve injury was compensated for by one or more of the following procedures: (1) Tendolysis, (2) free tendon grafts, (3) removal of sublimis tendons, (4) tendon transfers, (5) shortening or lengthening of the tendon, or (6) advancement of the proximal stump.

Preoperative requisites were good joint function, soft tissues for gliding, and strong muscle of the transferred tendons. It was also essential that sensation be present in the fingers selected for tendon grafts.

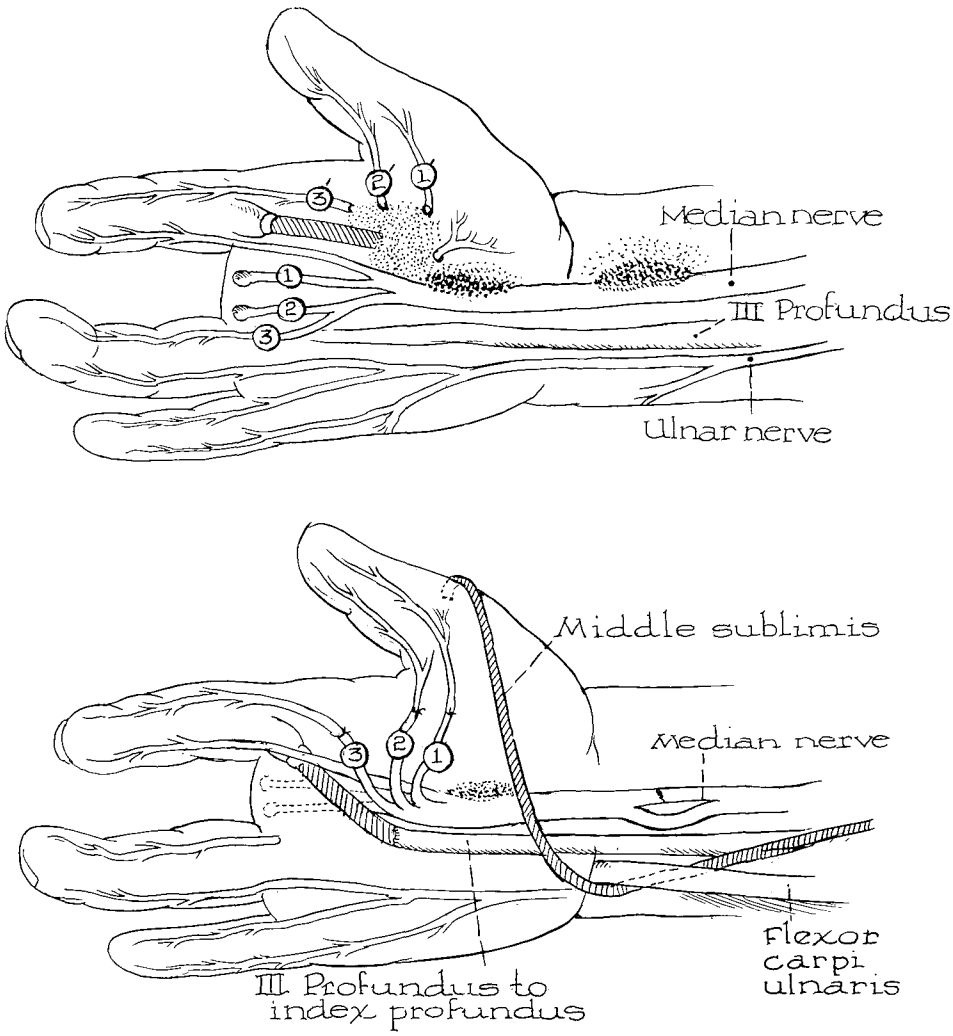



*Figure 125. Technique of nerve transfer to obtain sensation in thumb and index finger. Loss of the index profundus tendon and the opponens pollicis was overcome by transfer of the profundus and sublimis tendons of the amputated middle finger.*

*Tendolysis.* In numerous instances tendons were dissected free of scar tissue and an attempt made to form a gliding mechanism by transplantation of smooth fascia secured from the volar aspect of the wrist, the thigh or the tissue (paratenon) lying above the triceps tendon. After the scar tissue had been excised, the tendon could be freed from within its sheath by strong traction. It was then possible, if the joint were intact, fully to flex and extend the fingers.

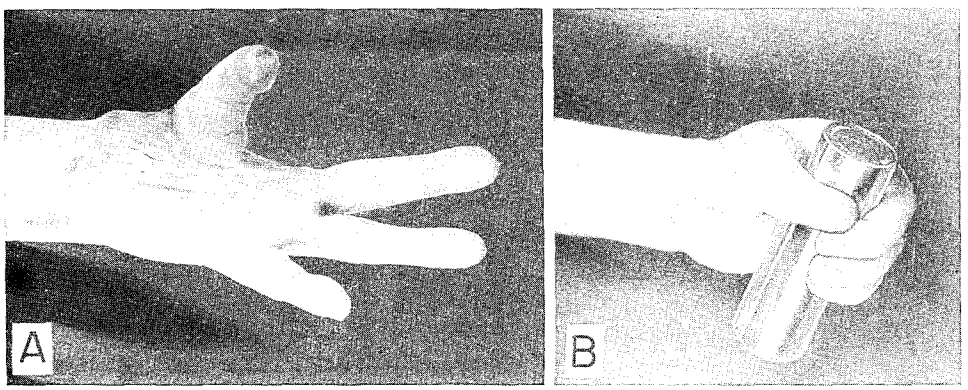



*Figure 126. Transposition of partially anesthetic index finger to compensate for total loss of thumb. The procedure included nerve suture, extensor tendon graft, and transfer of the sublimis of the ring finger for opposition. The terminal phalanx of the new thumb was amputated because of its excessive length. A. Hand in extension. B. Demonstration of function.*

After extensor tendons had been released, it was usually necessary to excise the collateral ligaments before joint flexion could be obtained. When long flexor tendons were intact but adherent to each other and to adjacent tissues, scar tissue had to be excised and a soft bed formed. When the sublimis and profundus tendons were adherent to each other and strong traction was applied, flexion occurred in the proximal interphalangeal joint only. The distal joint might flex slightly, but full flexion of the finger was lost. In a number of cases of this kind function was greatly improved by removing the sublimis tendon from the proximal portion of the palm to the proximal interphalangeal joint.

One technical point must be continuously emphasized: Anatomically there is a commissure in which the two divisions of the sublimis tendon, after dividing for the passage of the tendon of the deep flexor, are reunited for a short space. Below this commissure the tendon of the superficial flexor divides once more into two parts which pass to the lateral ridges of the middle phalanx. Unless this commissure is severed when the two divisions of the sublimis tendon are cut at the level of the proximal interphalangeal joint, proximal withdrawal of the sublimis tendon is difficult and the profundus mesotenon may be torn throughout its sheath. To provide more power, the proximal tendon of the detached sublimis was often sutured into the tendon of the profundus at the wrist.

Primary healing following the release of cicatrices usually occurred in from 7 to 10 days. Active motion was deferred until then. If begun earlier, healing tissues were disorganized and increased fibrosis resulted.

*Free Tendon Grafts.* Of the free tendon grafts placed, 43 were flexor grafts which extended to the terminal phalanges. Excellent function was obtained in 60 percent and good function in another 20 percent. The results in 3 of the flexor tendon grafts were not ideal, but the desire of the patients to keep their fingers prompted the performance of the operation. Tendon function returned in all 3 patients but was inhibited in each of these either by a poorly functioning joint or a malunited phalanx.

Free tendon grafts in selected cases proved useful in stabilizing a finger even when the full range of flexion was not obtained. Free grafts used to supplant the flexor pollicis longus were uniformly successful (Fig. 127).

Most patients who required free tendon grafts extending to the terminal phalanx also had injuries involving the distal aspect of the palm and proximal phalanges. These are locations unfavorable for tendon suture because the operation must be carried out in the region of the metacarpophalangeal pulley. Secondary tendon junctures were placed in only three areas of the hand and wrist: Just proximal, or just distal, to the transverse carpal ligament, and at the terminal phalanx.

Free grafts were immobilized for 3 weeks before active and passive motion was cautiously started. If the steel wire technique of Bunnell had been used, the wire was withdrawn at this time. The patient was given precise instruction in exercise of the affected finger. Immobilization of the metacarpophalangeal joint while active flexion was practiced was easily carried out by gripping the proximal phalanx with the thumb and fingers of the opposite hand and thus putting a pull on the interphalangeal joints. Wooden grip blocks measuring 2 by 2 by ¾ inches and various forms of occupational therapy were used during the first weeks after operation.

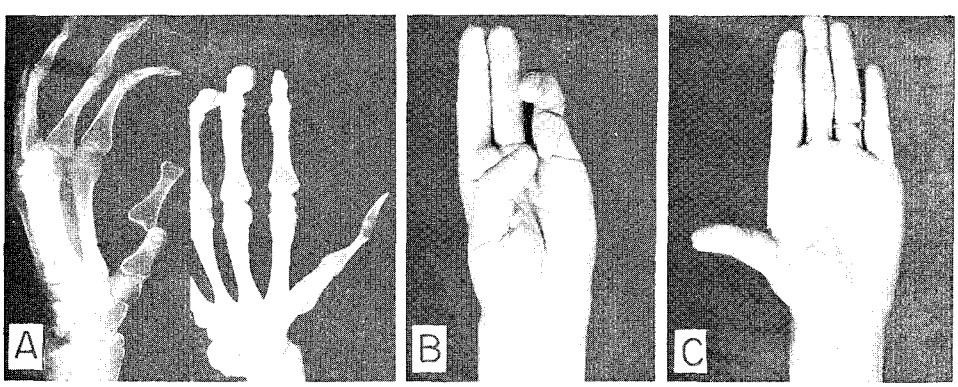



*Figure 127. Correction of destruction of distal metacarpal of thumb and rupture of pollicis tendon by metacarpophalangeal fusion and free tendon graft. A. Roentgenograms showing extent of bony defect. B and C. Postoperative range of function.*

If good progress had been made during the first 8 weeks after operation, the patient was sent on a work furlough to ensure constant use of the injured hand. It was both surprising and gratifying to see the progress in tendon function which had been made at the end of a 3-month work period (Fig. 128).

*Removal of Sublimis Tendons.* Since the sublimis tendon had to be removed whenever a flexor tendon graft was placed, the excised tendon was frequently used as a graft. Because its diameter was almost that of the profundus tendon, the sublimis tendon was particularly suitable for end-to-end suture. When grafts of small caliber (palmaris longus) were sutured end to end to the profundus tendon, the development of unsatisfied tendon ends was always a possibility. If the junction was placed at the origin of the lumbrical muscle, the suture line could be covered. Exploration of the proximal palmar junction in three tendon grafts which had resulted in poor flexion showed graphically how the use of tendon grafts whose caliber differed from that of the damaged tendon could produce unsatisfied proximal ends. The best results were obtained in tendon junctions when they were made with the same care as that employed in nerve sutures.

Assuring that the graft was of appropriate length for the amplitude required within the functional range was something of a problem. It was solved by threading the graft through the finger by means of a strong silk suture at the palmar juncture and then holding it with a hemostat to the stump of the profundus tendon while the finger was adjusted to the proper tension by checking it against a normal finger. A simple and effective test was to note the position of the fingers while the wrist was fully flexed and extended. If this test is satisfactory all fingers should flex and extend equally, and there

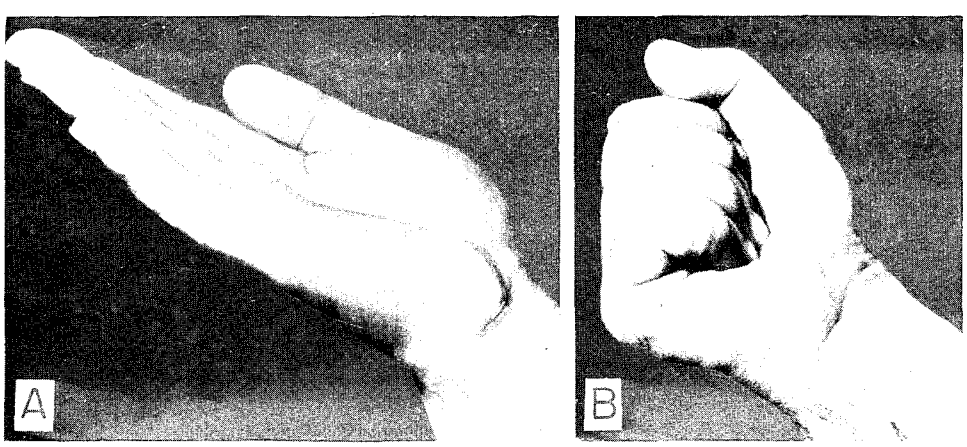



*Figure 128. Restoration by tendon graft (palmaris longus) of flexor tendon of little finger. Both flexors had been severed at the base of the finger. A. Finger in complete extension. B. Finger in complete flexion.*

should be some increase in the flexion of the fingers toward the ulnar side of the hand.

The tendon graft was always made somewhat longer than was apparently necessary because all grafts undergo some shrinkage after they are placed. On the other hand, some increase in muscle amplitude might compensate for a graft which was too short.

Injuries which involved the carpal tunnel and the area proximal to it frequently destroyed both the flexor tendon and the median nerve. In this type of case the continuity of the profundus tendons had to be restored by grafting. Grafts utilizing the sublimis tendon remnants could be obtained from the index, middle, and ring fingers, if they were of sufficient length. The proximal end of the graft was sutured to the profundus tendon in the midpalm while the two divisions were interwoven into the stumps of the proximal sublimis and profundus tendons. Individual grafts were used for the index and middle fingers, and the same graft was used for the ring and little fingers. The sublimis tendon of the fifth finger is usually too small to be used as a graft.

Whenever an important pulley had been destroyed, a loop of tendon was placed about tendon and bone to prevent the tendon from bow-stringing. It promptly became evident that only a single pulley should be reconstructed at the time of tendon grafting in any one finger if function was to be achieved. Important pulleys are located at the midportion of the middle phalanx and at the base of the proximal phalanx.

*Tendon Transfers.* In many cases tendon transfer proved extremely useful in restoring function to disabled hands. A redistribution of power where it was most needed restored muscle balance and thus improved function. The flexor tendon from any digit which had to be amputated could be used for any of the transfers to be described. Unfortunately, injuries involving the wrist and the base of the hand frequently left an unfavorable bed for the transferred tendon.

Tendon transfer was indicated in irreparable nerve injuries above the wrist and local loss of tissue. Thus, destructive radial nerve injuries, with resultant loss of extension, could be successfully compensated for by transfer of the flexor carpi radialis and ulnaris tendons to the extensors of the thumb and index fingers, and to the extensors of the middle, ring, and little fingers, respectively. Suture was carried out just proximal to the transverse carpal ligament. In a number of cases the palmaris longus was sutured to the abductor pollicis longus. When the arm and hand were long and slender, it was sometimes necessary to transfer the pronator teres to the extensors of the wrist. In one patient with this type of hand transfer of the two wrist flexors failed to effect adequate extension of the wrist, in spite of good extension of the thumb and fingers. Excellent functional results, however, followed transfer of the pronator teres at a second operation. A firm grasp is impossible without stabilization of the wrist in extension.

The technique was as follows: The operation was carried out with the hand flat and the wrist extended at an angle of 30 to 45 degrees. A dorsal curved incision was used, with the base of the flap on the radial side. The antebrachial fascia was exposed and the canal in which the extensor tendons course was uncovered by a rectangular excision. A fascial flap, with its base on the ulnar side, could be turned back and sutured to the ulnar aspect of the wrist to permit better gliding of the flexor carpi ulnaris tendon. If the extensor tendons were merely pulled through a tear in the antebrachial fascia and the flexor tendons brought around superficial to the fascia (as they must be), a restraining sheet of fascia was held at the apex of the juncture.

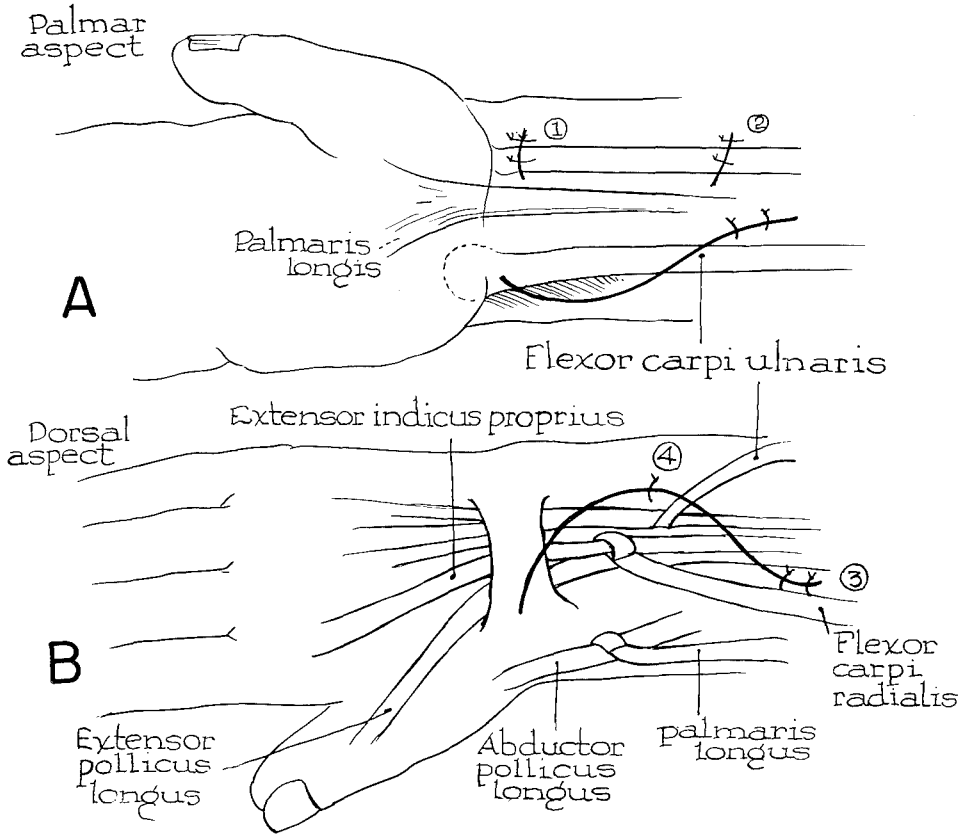



*Figure 129. Technique of tendon transfer for radial nerve paralysis. A. Incisions for tendon transfer (transfer of the pronator teres to the radial wrist extensors is not shown). B. End-to-end suture accomplished, with no loose tendon ends. C. Detail of end-to-end suture. D. Restraining effect of antebrachial fascia. E. Relationship of transferred tendon to antebrachial fascia and subjacent extensor tendons.*

The method of attaching the transferred tendon into the functionless tendon varied with the surgeon, but the end-to-end method was generally popular (Fig. 129).

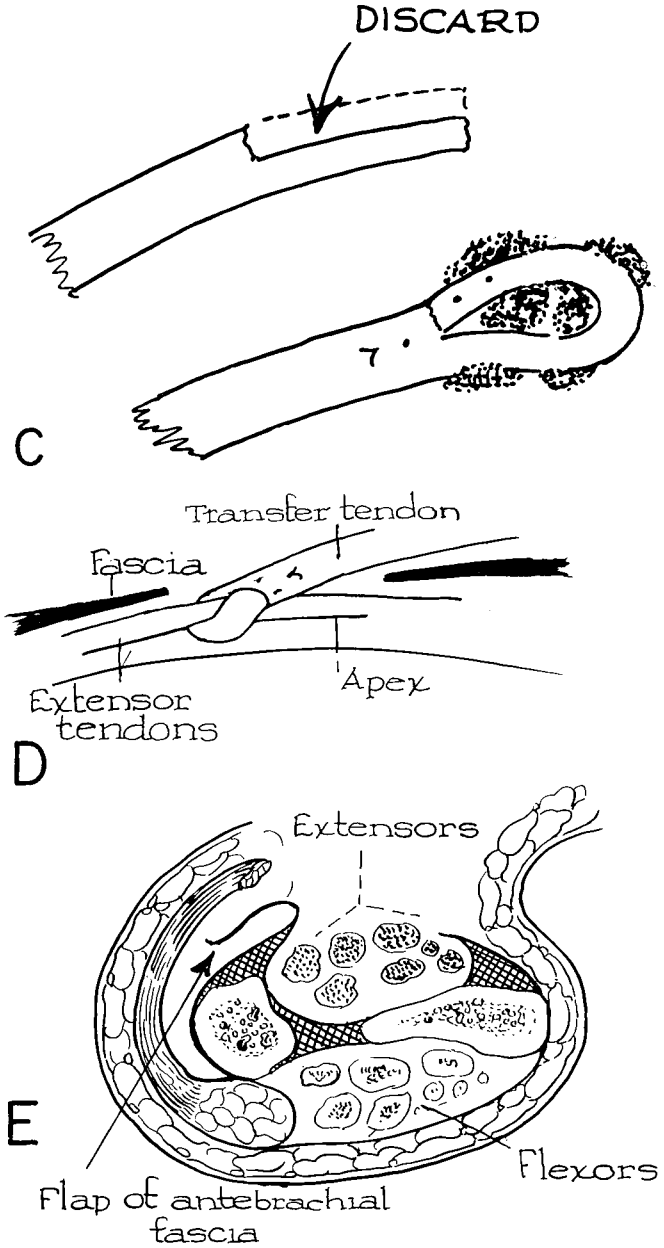



*Figure 129*—Continued.

Restoration of the power of opposition lost from nerve injury or local damage was accomplished by utilization of the sublimis tendon of the ring finger. The tendon was withdrawn at the wrist and passed around the flexor carpi ulnaris tendon and thence over the carpal ligament to the ulnar aspect of the proximal phalanx of the thumb. The short thumb extensor of a free graft could be used by bringing it to the ulnar aspect of the wrist and suturing it via a pulley, or under the flexor carpi ulnaris tendon, to one of the flexors.

The palmaris longus or the extensor digiti quinti proprius could be transferred to restore extension of the thumb when the nerve supply of the extensor pollicis had been disrupted or when its muscular portion had been destroyed (Fig. 130).

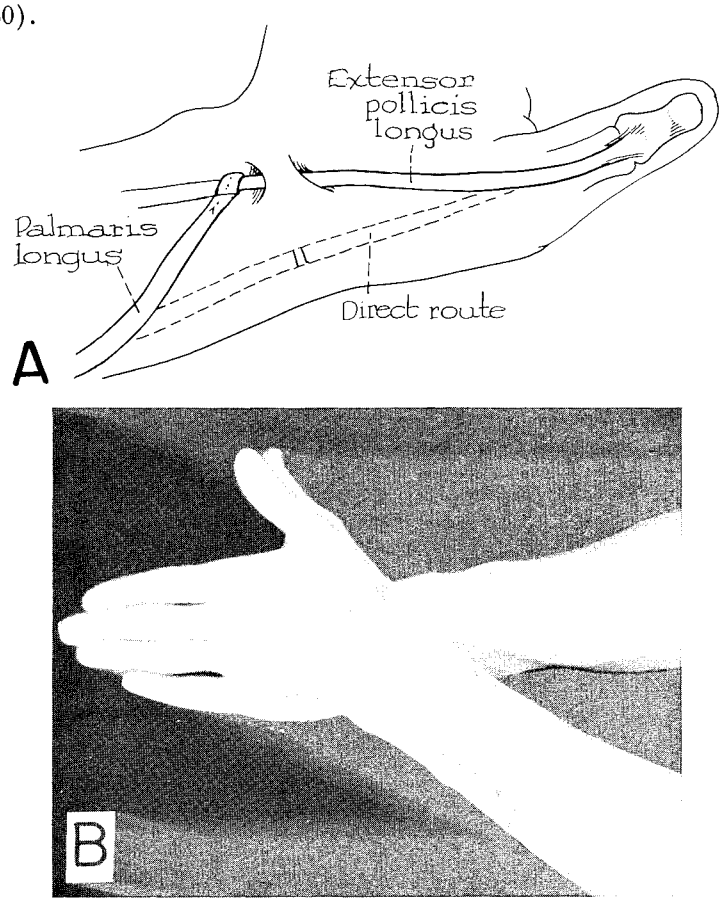



*Figure 130. Restoration of extensor pollicis longus function by transfer of palmaris longus by direct route, after destruction of muscle by local injury. A. Technique of transfer. A more direct pathway could be gained by removing the extensor tendon from the radial canal and accomplishing an end-to-end suture with the palmaris longus. B. Complete restoration of extensor function.*

In one patient in whom a middle ray had been removed and the first dorsal interosseus paralyzed, the sublimis tendon was passed subcutaneously over the fovea radialis through the groove between the first and second metacarpals and then sutured to the abductor tubercle on the proximal phalanx of the index finger. The adduction deformity was thus eliminated and powerful abduction of the index finger obtained (Fig. 131). Bunnell's method of

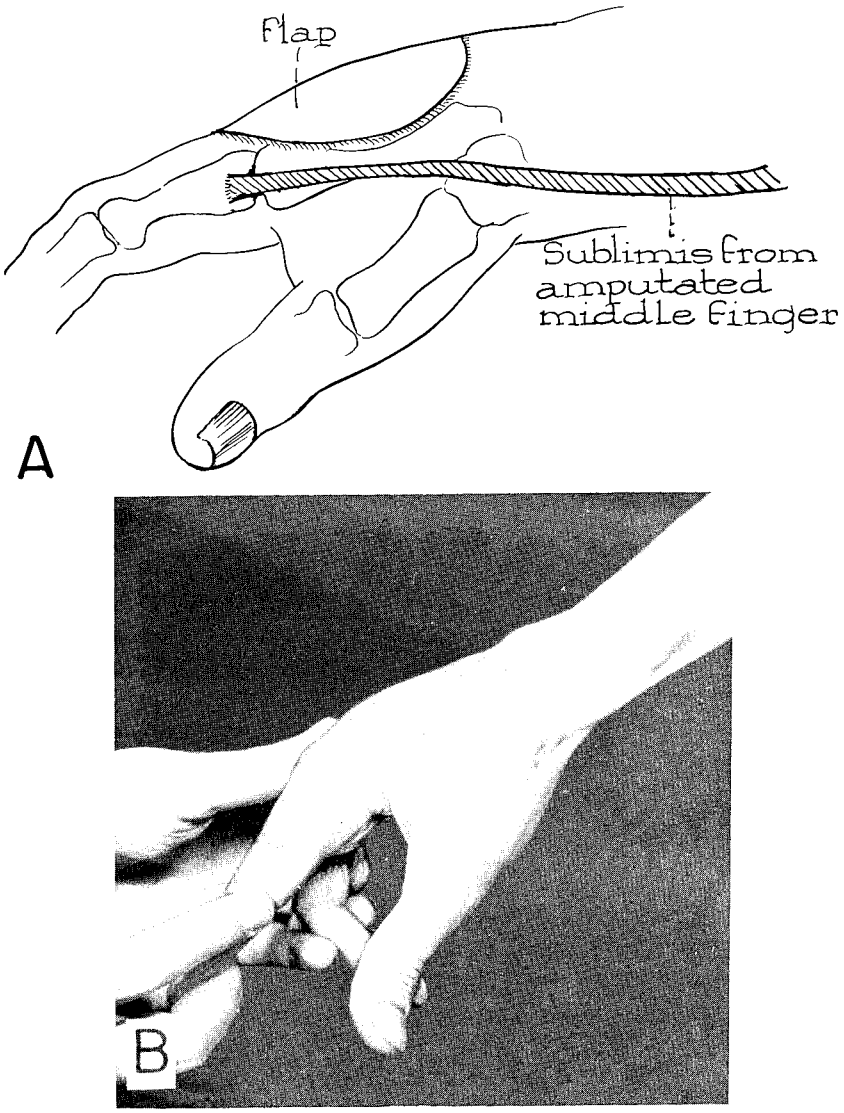



*Figure 131. Transfer of sublimis tendon from amputated middle finger to index finger. A. Diagram of tendon transfer. B. Functional result. Note strength of abduction of index finger by transferred tendon.*

using the extensor indicis proprius for restoring abduction of the index finger (Chapter II, p. 56) was employed in several instances in two of which incomplete extension of the finger resulted secondary to loss of the proprius.

*Shortening or Lengthening of the Tendon.* Tendon lengthening was carried out at the wrist in injuries involving the ulnar aspect of the forearm; ulnar nerve paralysis was usually associated.

Damage to the muscular portion of the flexors did not lend itself to surgical correction. If, however, the muscle had become shortened by loss of substance and resulting cicatricial contracture, a tendon graft placed at the proximal end of the tendon proved a most satisfactory method of repair. After healing of the graft, the hand was splinted in flat extension at night. The injured fingers were usually tightly flexed when the hand was extended but could be opened following the interposition of a graft. Ulnar nerve damage with instrinsic muscle paralysis frequently prevented extension of the middle and terminal phalanges, especially of the fourth and fifth fingers, and thus enhanced the flexion contracture of the fingers secondary to flexor tendon shortening.

Arthrodeses were often necessary in partially paralyzed hands to provide stability and to make tendons available for transfer.

## AMPUTATIONS

Amputation of one or more digits was often required to liberate the remainder of the hand from the crippling effects of functionless fingers.

When, for instance, a metacarpal bone was badly shattered and the head and metacarpophalangeal joint were involved in the injury, the finger was shortened and often rendered useless. The extensor and flexor tendons might be lost, together with the volar nerves. Local damage always greatly impaired the function of the interossei, and extension of the terminal phalanges might be lost. If the metacarpal of the middle or ring finger was involved in the injury and the head destroyed, the practice was to remove the entire ray.

If the third or fourth rays had been lost, the palmar arch was also lost and crossing of the adjacent finger resulted on flexion. The whole hand was therefore crippled (Fig. 132 A). The functional disability was greatly reduced, and a useful hand obtained, by shifting the base of the second or the fifth metacarpal into the position of the lost adjacent metacarpal (third or fourth). A Kirschner wire was used to hold the base of the transposed metacarpal in its new position. When the extensor tendons of the wrist were dissected off the base of the metacarpal, steel wire fixation was necessary to hold them in their new position (Fig. 132 B). The proximal phalanx of the amputated third or fourth finger could be recessed to fill the metacarpal gap and restore the palmar arch by preventing rotation of the adjacent metacarpal heads. Results were good in the two patients in which this technique was employed.

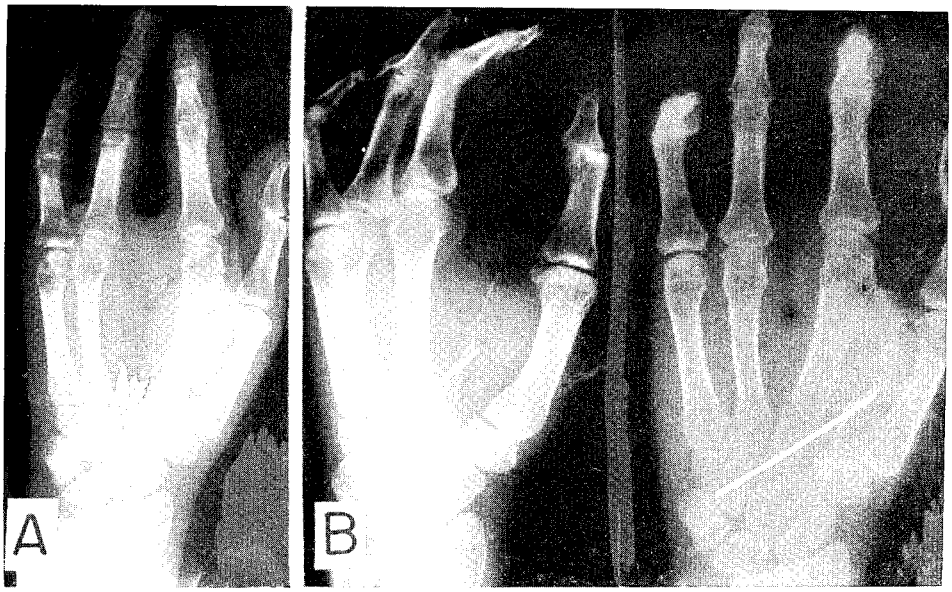



*Figure 132. Correction for loss of third ray. A. Roentgenogram showing crossing of fingers resulting from loss of ray. B. Postoperative roentgenograms after shifting of base of second metacarpal to base of third, with Kirschner wire fixation. A steel wire suture holds the extensor tendons of the wrist in position.*

When either the index or little finger had to be amputated, a cosmetically better result was secured if the metacarpal was resected obliquely at its proximal third. Flexor tendons were sutured at correct tension or severed as far proximally as possible to prevent a palmar checkrein on the remaining fingers. The digital nerves could be brought to the dorsum of the hand between the metacarpals, the nerve end being buried in the interossei. But with this technique troublesome palmar neuromas were unlikely to occur.

If the injury was limited to the digit, partial amputation was usually practical. It was the custom at Cushing General Hospital, when either the third or fourth finger was irretrievably injured but the metacarpal bone intact, to limit surgery to metacarpophalangeal amputation. The gap between the fingers was not unsightly, and function was excellent if the other fingers were intact.

Before any digit was amputated, the possibility of salvaging any of its undamaged structures was always carefully considered. Often a nerve or a tendon could be transferred, or the skin used for resurfacing a badly scarred area on the hand.

*Transposition of Fingers.* In seven patients observed at Cushing General Hospital the index finger was transposed to compensate for the loss of the thumb

(Fig. 133). The procedure was carried out in two stages. Plastic surgeons separated the second and third metacarpals and placed an abdominal pedicle flap between the two bones. Later, on the orthopedic hand service, the transposed digit was repositioned and fixed in the position of function.

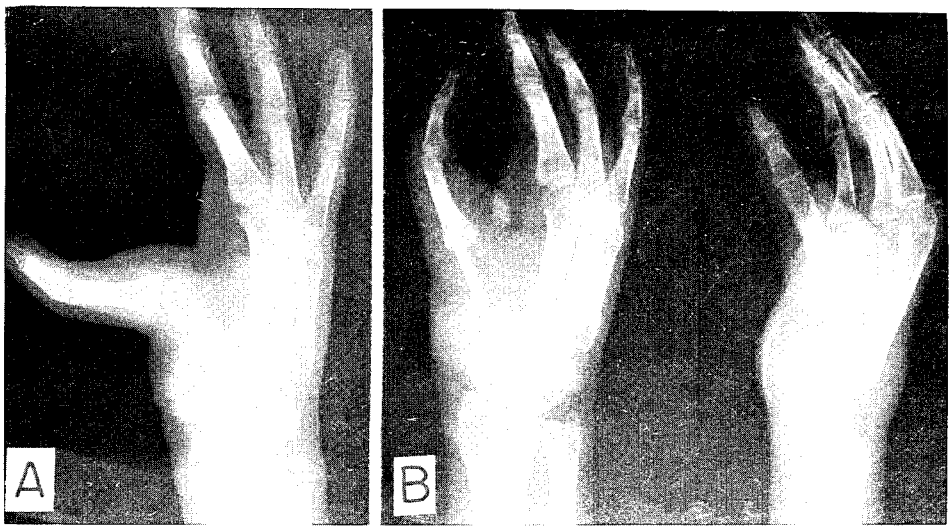



*Figure 133. Transplantation of index finger to compensate for loss of thumb. A. Roentgenogram showing preliminary transposition of index finger for reconstruction of thumb. B. Roentgenograms showing bone graft stabilizing index finger transposed to correct complete loss of thumb.*

## REHABILITATION

The skill and judgment employed in surgical procedures did not terminate the treatment or fully discharge the responsibilities of the surgeons concerned. Accumulated experience demonstrated that true evaluation of ultimate results in these cases could be made only after prolonged treatment and use of the damaged hands and the lapse of considerable time after the completion of surgery.

In order to restore function and maximum usefulness there were required, in some cases, considerable periods of corrective splinting. In almost all instances, manipulative physiotherapeutic procedures were required and particularly controlled and directed active exercise of the hand. Perhaps the most effective means of restoring function, and the method generally used to supplement the other methods, were to be found in occupational therapy.

Methods of corrective splinting have been quite fully described elsewhere. When residual stiffness of joints or restricted range of motion required correction, the appropriate types of splints continued to be employed after surgical

repair, at first for protection, subsequently for re-establishing the fullest possible range of motion. When splints were used in this manner they were employed intermittently and the splinting was supplemented by daily exercise, and physical and occupational therapy, the splints being temporarily removed for these purposes.

Manipulative physiotherapeutic measures were found to have their greatest value during a period of 2 weeks to a month following the healing of surgical wounds. In cases of nerve injury with paralysis of the muscles controlling the activities of the hand, both protective splinting and physiotherapeutic measures had to be continued for long periods of time, until effective reinnervation had taken place.

Physiotherapeutic measures most favored included (1) the application of heat by means of lamps, diathermy (employed very cautiously), soaking in hot water, baking, and paraffin baths; (2) the whirlpool bath, in which the hand was immersed in agitated water for periods of 20 to 30 minutes which provided some of the benefits of heat, soaking, and light massage, while at the same time the patient was encouraged to move and exercise his own hand and fingers; (3) massage, light stroking and rubbing of the hands and fingers, usually after some method of application of heat; and (4) selective electrical muscle stimulation. All of these procedures had the same objectives, to restore, maintain, or improve, the tone and circulation in the injured hand, with resultant improvement of tissue metabolism induced by increase in blood flow.

Manipulation by physiotherapists, in an endeavor directly to promote mobility of stiffened joints by passive motion, was not encouraged. The forceful manual manipulation of joints, unlike the slow, gentle, persuasive effect of the elastic forces of approved corrective splints, served only to exaggerate pain, evoke a responsive muscular spasm, and, if persisted in, to result in tissue damage and subsequent increased stiffness of the joints.

In marked contradistinction to these results were the beneficial effects of directed active motion. Ward officers on the hand services were trained to spend a good deal of time in individual instruction of their patients in the movements best calculated to diminish their individual disabilities. When this duty was conscientiously performed, they were rewarded by gratifying improvement in their patients. It was necessary to explain carefully and in detail the method and purpose of each exercise and to secure the intelligent cooperation of patients in their consistent and faithful performance.

Perhaps the most dramatic example of the efficiency of this method was the loosening of repaired or grafted flexor tendons when the presence of firm healing had been assured. With the proximal phalanx of the affected finger firmly supported in midflexion, the patient was directed to exert his own full power in an effort to flex the finger fully. Time and again, in the performance of this exercise, the patient and surgeon would become aware of the tendon's sudden

release, with a gratifying immediate marked increase of the range of active flexion.

In addition to free exercises, a variety of appliances were devised for providing resistance exercises of the hand's intrinsic and extrinsic muscles. The simplest of these were rubber balls, sponge rubber grips, or simple spring devices to be held in the palm and squeezed. More elaborate apparatus for exercising the hand were provided for use in physical therapy departments and gymnasia for corrective exercise.

Of all the measures for rehabilitation of the disabled hand, occupational therapy brought about the most satisfactory improvement. While many ingenous methods of employing the hand were devised in various hospitals, all had the same purpose—that of putting the injured member to work. The simplest and not the least successful application of this principle was in the occupations of everyday living. Characteristically, the patient from long habit tended to spare and protect the injured extremity and to use the other hand whenever possible. Often the hand was held in an awkward position, or was supported, cradled, or allowed to dangle, its helplessness increasing day by day. Patients were advised, encouraged, and even coerced into using the injured hand to the greatest possible extent, even to the exclusion of the good hand. Though movements were awkwardly made at first, patients were persuaded to use the injured hand in opening doors, picking up objects, writing, shaking hands, eating with knife and fork, and all the natural maneuvers of everyday existence. Results of the change in habit and of increasing use of the hand were always gratifying and often surprisingly effective.

CHAPTER X

# Hand Surgery at Dibble General Hospital

*Donald R. Pratt, M. D.*

## ADMINISTRATION

Following the establishment of the plastic service at Letterman General Hospital in June 1943 [1] all patients with hand injuries were treated on that service until April 1944 [2] when it was transferred to Dibble General Hospital. In February 1945 a special hand center was set up at Dibble as a subsection under the orthopedic surgery section.[3] During the 8 months of operation which followed some 1,200 patients were treated there. Details of administration were essentially the same as at other hand centers.

Methods of procedure were based on the most modern developments in general, orthopedic, neurosurgical, and allied fields. Success depended upon a complete knowledge of regional anatomy, a careful atraumatic technique, and a supervised postoperative course. The end result was restoration of function in an unexpectedly large proportion of hand injuries.

Use of arm boards and pneumatic tourniquets was routine; stools were provided for the surgeons. Complete teamwork in the operating room was essential. With it, an atraumatic technique and rapid surgery made possible doing multiple procedures at the same operation—a combination of excision of the scar, bone graft, and capsulectomy, or capsulectomy on the proximal joints with nerve and tendon sutures in the palm.

## DRESSINGS AND SPLINTS

Unnecessary crippling was often encountered because injured tissues had not been adequately supported soon after injury. Good motor function in the hand depends upon the presence of (1) a wrist stable in dorsiflexion, (2) an opposable thumb for pinch and grip, (3) full flexion of the fingers and thumb for grasping, (4) ability to fix the fingers in partial flexion to act as a hook, and (5) extension to open the digits for grasping. These requirements were sometimes lost by improper splinting and had to be borne in mind when splinting was undertaken.

For effective immobilization splints or casts must be form fitting and include at least two-thirds of the circumference of the limb. The hand was best

[1] Annual Rpt, Letterman Gen Hosp, 1943. HD.

[2] Ltr, CG ASF (SG) to CG 9th SvC, 31 May 44, sub: Transfer of specialized facilities. SG: 323.7–5.

[3] Annual Rpt, Dibble Gen Hosp, 1945, p. 31. HD.

immobilized in a plaster of paris cast, or, if available, a well-fitting metal or plastic splint. It was necessary that bones and joints be maintained in the position of function and that the splint include the joints immediately above and below the fracture site. If fragments were not stable when reduced, skeletal traction or fixation by means of a nonpadded or lightly padded cast had to be resorted to. A surgeon whose experience with plaster was limited chose the wiser course if he used padding—also advisable if the injury was recent.

Generally, the most useful type of nonpadded cast consisted of plaster splints on the dorsum and on the volar aspect of the forearm, wrist, and hand, molded into place with the hand in the position of function by a roll of bias muslin bandage. When the plaster was firm, the bandage was cut longitudinally. If circular plaster bandages were applied, the cast was completely bivalved. These precautions prevented the development of gangrene of the digits and of Volkmann's ischemic contracture, and also made dressing of the wound a very simple matter. The importance of splitting the cast as soon as it was applied was constantly emphasized, as was elevation of the hand. These precautions prevented dependent edema from casts and dressings which were too tight, ischemia, necrosis, and gangrene. It was essential that the cast be split as soon as it had become firm, for swelling is greatest immediately after injury, and the complications mentioned are then most likely to occur.

Plaster of paris had a number of special uses in splinting of the hand. After repair of flexor tendons a dorsal plaster slab was used to hold hand and wrist in moderate flexion; the fingers were not acutely flexed. After repair of extensor tendons of the wrist, fingers, or thumb, a volar slab was used to maintain extension. An encircling cage of wire ladder splint incorporated in a nonpadded cast afforded an open air dressing (Fig. 134); the hand could be wrapped in gauze to furnish adequate protection from injury.

The banjo type of splint which incorporates traction with extension was universally condemned. Its straight pull on the fingers in extension leaves them stiff and malunion of fractures is usual; when it is used in flexion, the line of pull is wrong and places a strain on the fingers. In the normal hand, or in the properly immobilized injured hand, the digits flex to converge toward a single point.

Two types of metal splints for the wrist were used. One was a volar cock-up wrist splint with a forearm plate and a pad in the palm. The other was a dorsal metal wrist splint composed of three cross plates on a longitudinal rod molded to the contour of the hand and forearm. When this was used, care had to be exercised not to produce a flat hand. For the hand proper, a triangular metal splint could be used in the palm, or a slightly curved splint strapped to the dorsum of the hand. Aluminum gutter splints formed to fit the fingers, with varying angles of flexion, could be applied either to the dorsal or volar aspect of the injured finger.

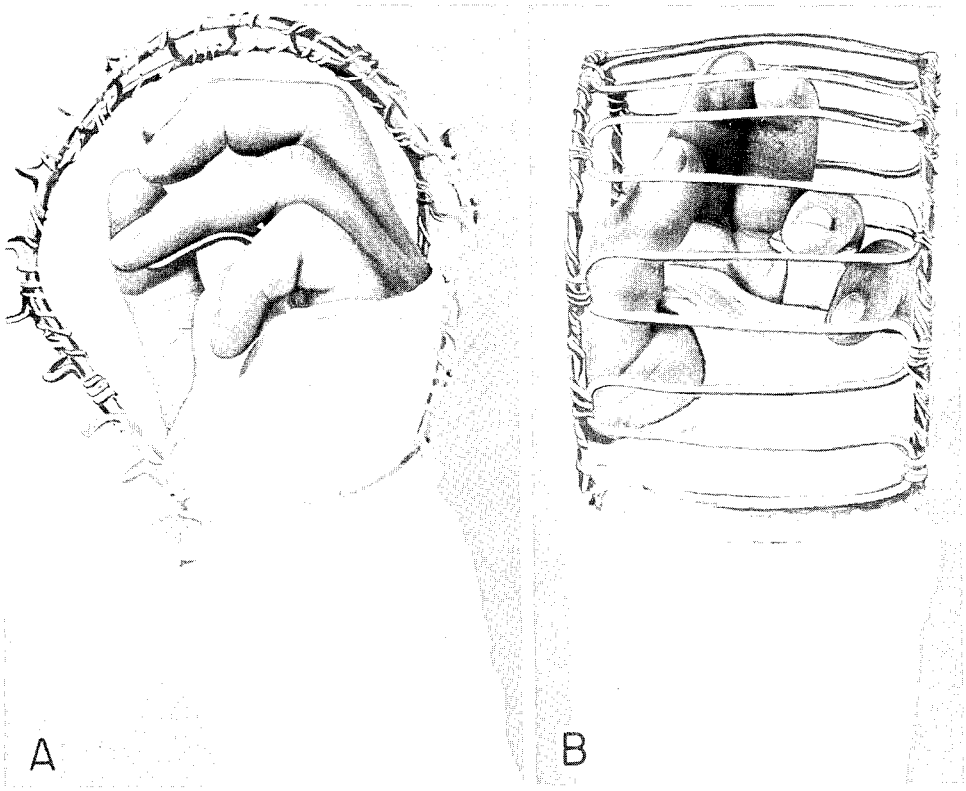



*Figure 134. Cramer wire air dressing cast. A. Palmar view. B. Lateral view. Note that the ring finger is supported by a metal gutter splint while the adjacent fingers and thumb are free to flex and extend fully.*

In splinting injuries of the radial nerve the wrist was supported in dorsiflexion and proximal segments of the finger and thumb in moderate, but not extreme, extension. It was necessary that this splint be removable or, in the case of fractures proximal to the metacarpals, that the portion extending beyond the metacarpophalangeal joints be removable, to permit daily motion of the fingers. This type of immobilization prevented contractures until a spring wire or elastic traction type of splint, which permits constant motion, became available. Mobile splinting with a light spring wire or elastic bands maintained intrinsic muscle tone following nerve suture, especially suture of the deep motor branch of the ulnar nerve and the thenar branch of the median nerve.

Prolonged and too extensive immobilization, or immobilization in a faulty position invariably results in atrophy and stiffening of the hand, with permanent crippling due to loss of function of the fingers. These dangers were

constantly borne in mind at the Dibble Hand Center. Actually, no difficulty was experienced in combining the two principles of immobilization of the injured part and mobilization of uninvolved joints. Function of the wrist could be maintained adequately by finger exercises, and if supported in the proper position, immobilization of the wrist proper was not a serious problem.

Both before and after operation various prosthetic devices were found useful. A simple web or leather strap served to maintain complete range of flexion in the digits. A clock-spring wire extension splint (Fig. 10) was designed and used at Dibble General Hospital to obtain extension in all the joints of the thumb and digits. A cock-up wire splint (Fig. 135) obtained dorsiflexion of the wrist. A soft leather elastic cot was placed about the thumb to increase the thumb bed, obtain and maintain a position of opposition for the thumb, and increase the passive range of extension and flexion in the two distal joints of the pollux. Bunnell's knuckle bender splint provided flexion of the metacarpophalangeal joints and the two distal joints of the fingers; this type of splint is adjustable, affords constant traction, and permits exercise. Finger cots were used on the basic cock-up splint. A light spring wire splint was employed in radial nerve palsies to permit support of the thumb and fingers yet afford flexion to the finger joints to eliminate stiffness and contractures.

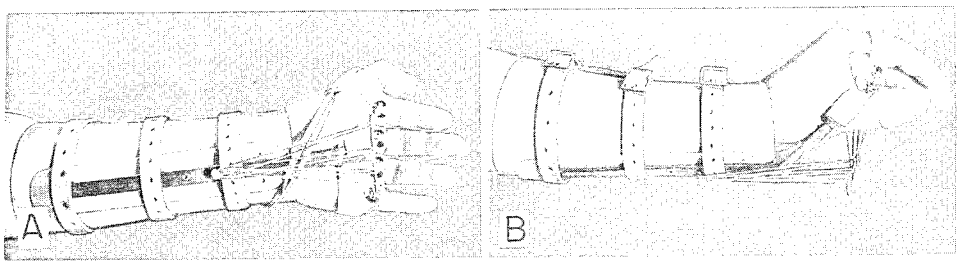



*Figure 135. Splint designed to achieve dorsiflexion of wrist, flexion of metacarpophalangeal joints, and opposition of thumb. A. Palmar view. B. Radial view.*

## SKIN REPLACEMENT

Early closure of wounds with split thickness grafts reduced infection and scar tissue formation. As a result, bone graft, tendon suture, nerve suture, or other necessary procedures could be performed more promptly. Split thickness skin grafting was particularly useful for early covering of the clean granulating surfaces of burns (Fig. 136) as it minimized contracture of digits, avoided the buttonhole deformity otherwise frequent in interphalangeal joints, and prevented both the claw hand resulting from a

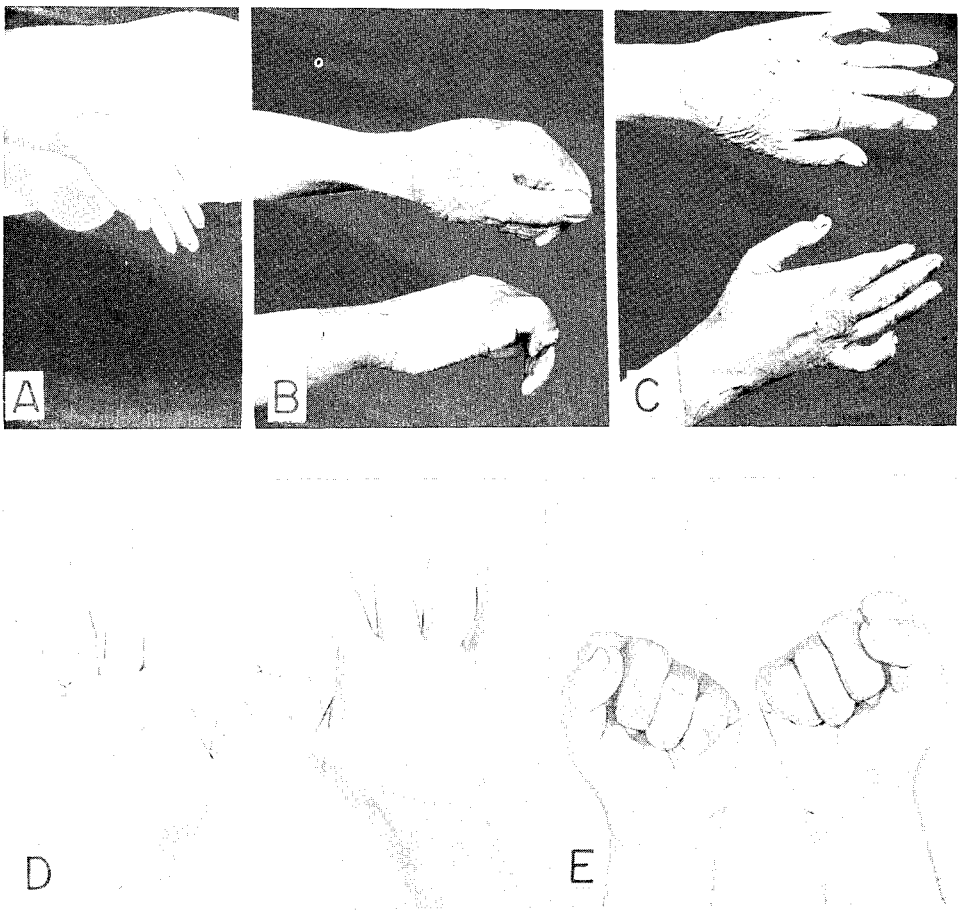



*Figure 136. Use of thick split skin grafts in superficial scars. A. Greatly thickened keloid on dorsum of right hand following third degree burns. B. Condition of right hand 7 days after first stage excision of scar. Note blanching of thickened scar over proximal joints of left hand when hand is closed. C. Condition of right hand after portion of keloid has been removed from dorsum. Keloid on dorsum of left hand has not yet been removed. D. Condition of both hands after thick split grafts have been applied to dorsal aspects of hands and fingers. E. Functional result.*

cicatrix across the dorsum and the flat hand which follows contracture of the thumb web. Thick split skin grafts were necessary for good covering of joints before repair of extensor mechanisms and release of stiffened joint capsules were undertaken to relieve contractures.

Application of full thickness skin and subcutaneous tissue by direct pedicle flap (Figs. 137, 138, and 139) or flap shifts (Fig. 140) cut down by several

months the period of hospitalization and disability. Whenever possible, direct flaps from the abdomen were used on the dorsum of the hand, on the fingers, and about the thumb web and the wrist. When direct flaps could not be used, a tubed pedicle graft was employed (Figs. 141 and 142).

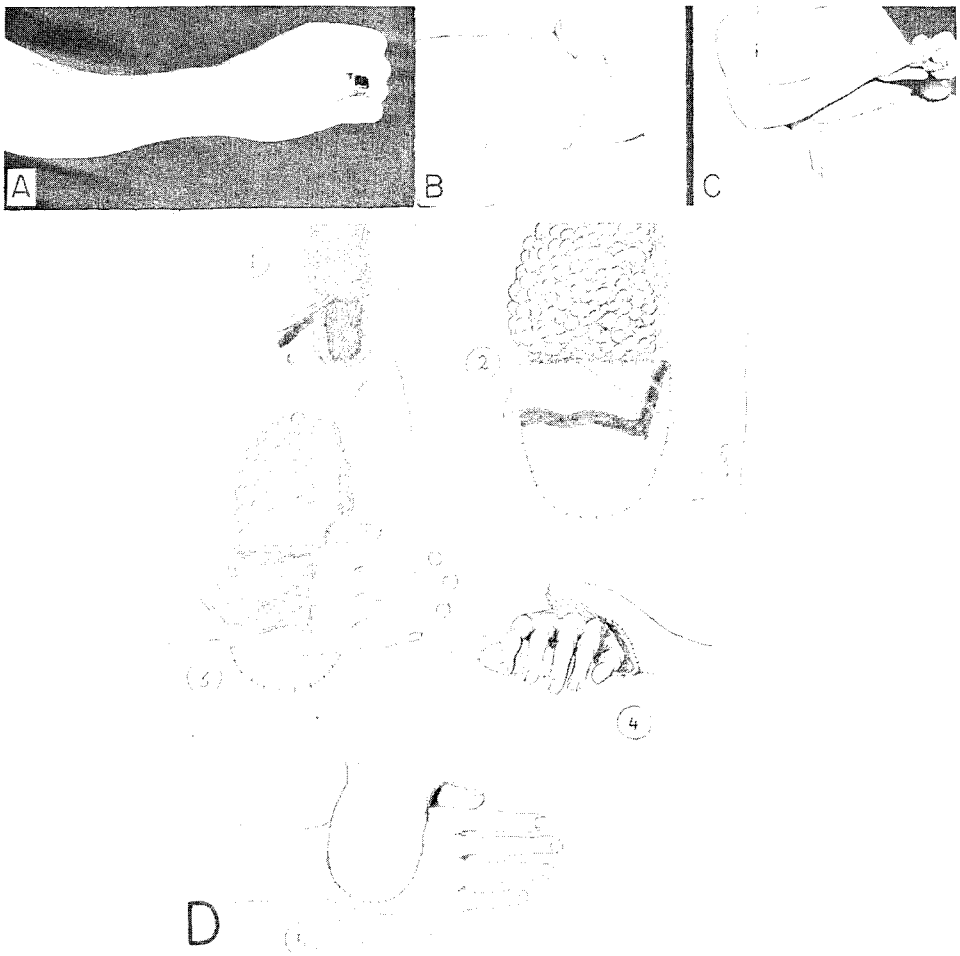



*Figure 137. Use of direct flap completely lined with thick split skin graft. A. Deformity of forearm secondary to shell fragment injury which resulted in loss of extensor tendon and fracture of radius with loss of bone. Skin and subcutaneous tissue must be supplied before bone grafting and extensor tendon surgery can be undertaken. B. Appearance 10 days after direct application of abdominal pedicle to dorsum of arm. C. View of thick split graft applied to under surface of pedicle at first operation to cover defect of abdominal wall. D. Technique of attachment of direct pedicle with thick split graft lining.*

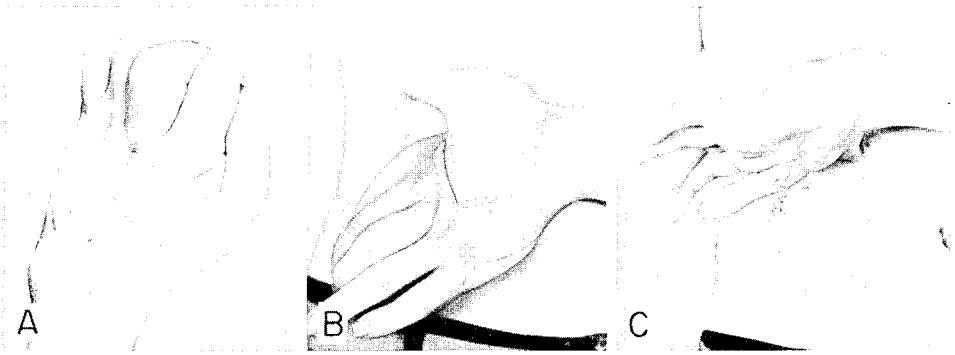



*Figure 138. Use of direct flap completely lined by thick split skin graft. A. Appearance of hand after primary operation following injury from gunshot wound causing fracture of metacarpals and loss of extensor tendons. B. Direct application of abdominal pedicle to dorsum of hand. C. Defect of abdomen and under surface of pedicle covered with thick split graft thereby eliminating any open wounds.*

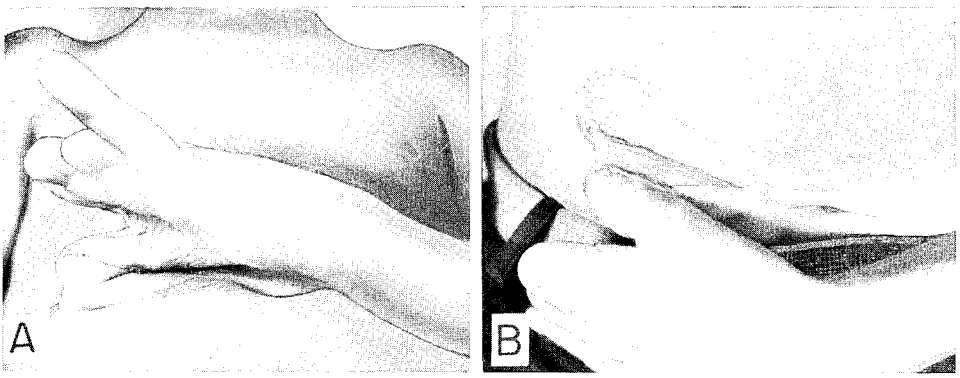



*Figure 139. Use of direct flap completely lined by thick split skin graft. A. Direct application of pedicle to furnish skin and subcutaneous tissue to injured thumb. B. Under surface of pedicle lined with thick split graft. Because there is no open wound the initial dressing has not been replaced. This picture was taken on the seventh postoperative day.*

## BONES AND JOINTS

The availability of penicillin and the sulfonamides, and use of atraumatic techniques made it possible to perform bone operations in injured hands within fairly short intervals after wound closure. Osteomyelitis was treated by sequestrectomy, adequate drainage, massive lukewarm boric acid compresses, and maintenance of the hand in the position of function. Foreign bodies, such as pieces of metal, or silk and cotton sutures which caused draining sinuses, were removed.

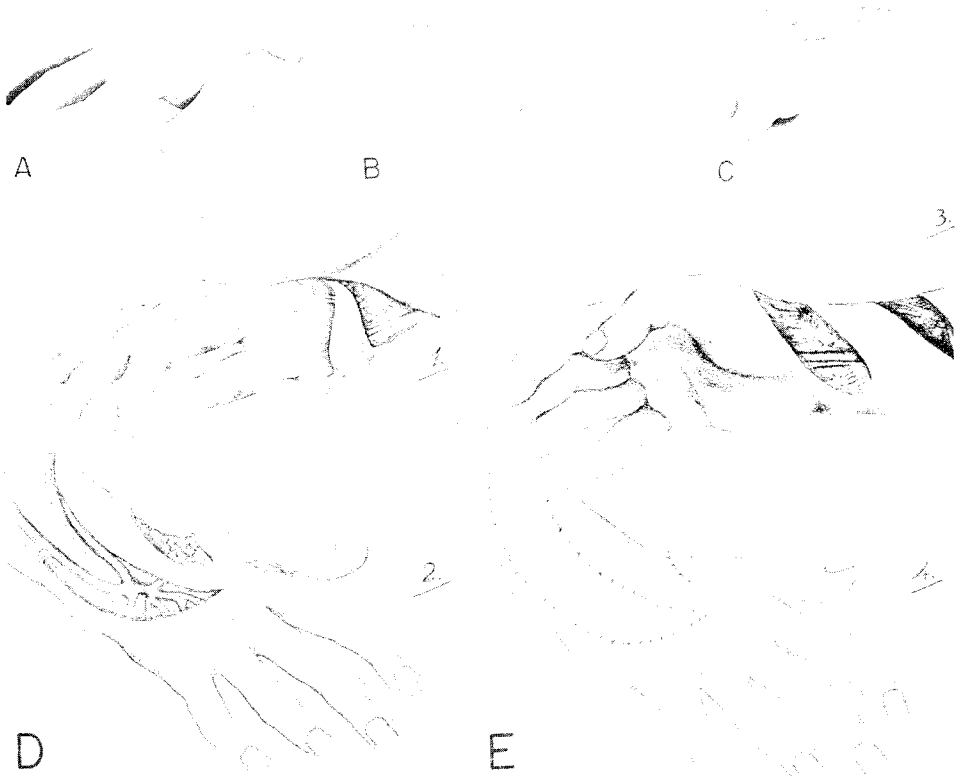



*Figure 140. Use of flap shift supplemented by thick split skin graft. A. Scarring of right hand after shell-fragment wound, which caused loss of extensor tendon to thumb. Skin and subcutaneous tissue must be supplied before tendon graft can be accomplished. B. Hand after application to defect of double-pedicle flap shift with thick split graft. C. Hand in position of function. An extensor tendon graft to the thumb can now be inserted. D and E. Details of technique.*

A new type of bone graft was introduced in the form of cancellous bone. This afforded more rapid healing and because of its increased vascularity prevented sequestration or nonunion. At the Dibble Hand Center 30 iliac bone grafts were performed for metacarpal fractures or deformities and for intramedullary pegs or for flat grafts in the phalanges.

The moving of all uninjured parts while the injured one was immobilized led to the use of removable stainless steel wire pins in the treatment of fractures or bone grafts in hands (Figs. 143 and 144). Removable longitudinal wires were eventually used on all metacarpal bone grafts. They were placed down

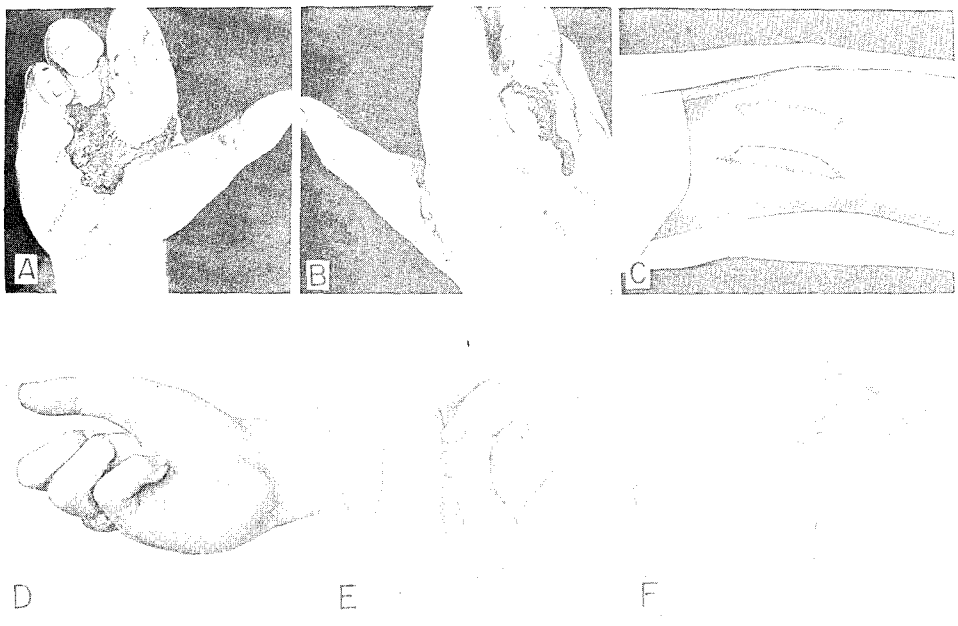



*Figure 141. Use of tube pedicle formed by split graft. A. Injury of right hand by land mine, the damage including metacarpal injuries, soft tissue destruction and tendon injuries. B. Dorsal view. C. Thoraco-epigastric tube pedicle on seventh postoperative day, showing thick split graft beneath tube. D. View of hand after application of thick split graft. Contractures make it impossible to extend the fingers or abduct the thumb. E. Tube pedicle in place. Functionless middle finger has been amputated. Note that thumb can now be abducted. F. Functional result. This patient had excellent grasping ability.*

through the shaft of the bone, cut off to prevent any irritation of the cartilage on the metacarpal head, placed through the proximal end of the shaft and were so inserted that they could be withdrawn at the wrist by making a tiny nick in the skin. Full mobilization of the interphalangeal and metacarpophalangeal joints was thus possible during immobilization and a pliable hand maintained.

In some instances removable transverse double wires were placed across the distal ends of the metacarpals to prevent dropping of the heads into the palm. By this means rotation torsion of the fracture site or graft was also prevented during exercise of the fingers and the normal carpal arch was maintained.

Capsulectomy at the time of primary bone graft made it possible to place the hand in the position of function. By the use of cock-up splints and finger cots the hand proper could be immobilized while the fingers and thumb were mobilized. By the time the stainless steel Kirschner wires were removed a

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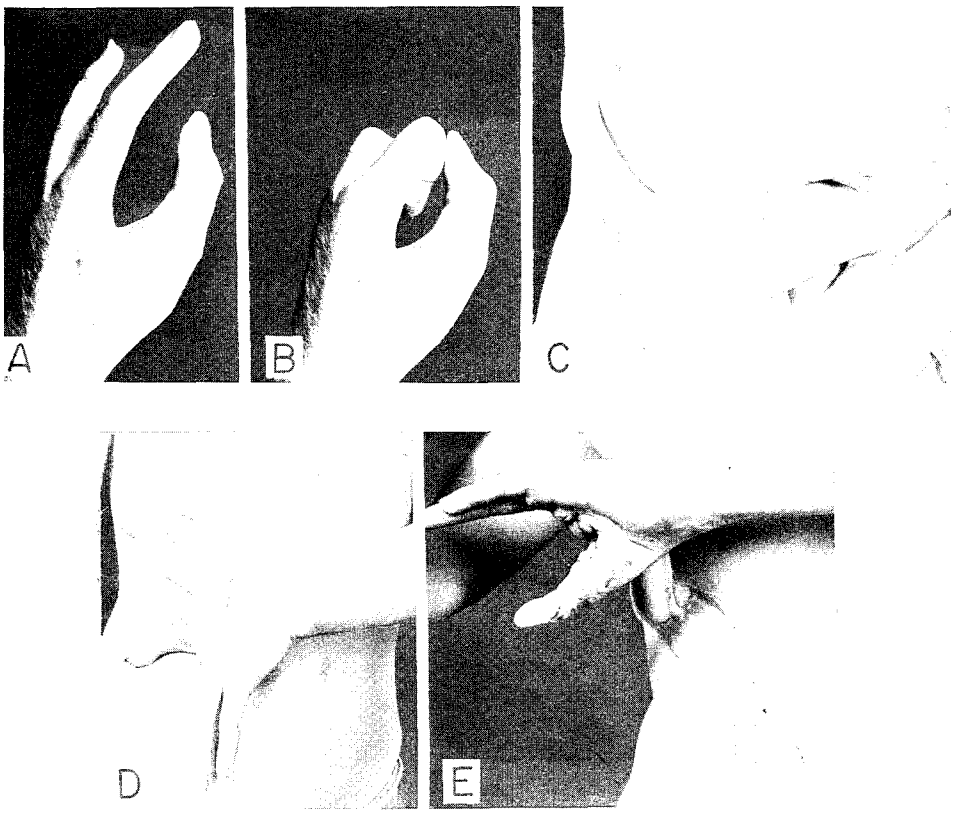



*Figure 142. Use of tube pedicle with split graft. A. and B. Shell fragment injury of hand resulting in loss of index and middle fingers. Note the contracture decreasing the web space of the thumb and ring finger. C. Thoracoepigastric tube pedicle with split graft beneath, showing primary and secondary delays of flap. D. Tube pedicle attached to hand. Note increase in thumb-finger web space. E. Split graft applied at angle of tube. F. Technique of attachment of tube pedicle flap with small hinge flap. The flap assists in increasing the web space. G and H. Increased thumb-finger web space and good functional results.*

useful range of motion was present. In a series of 75 bone grafts these various improvements were all evident, final function was much better than under older methods, and the period of hospitalization was reduced.

## OPERATIONS ON THE FINGERS

Skin for other fingers was supplied by fillet of severely damaged ones (Figs. 145 and 146). In 44 instances of severe damage to one of the outer rays, the index or the little finger was amputated and the skin used in this way.



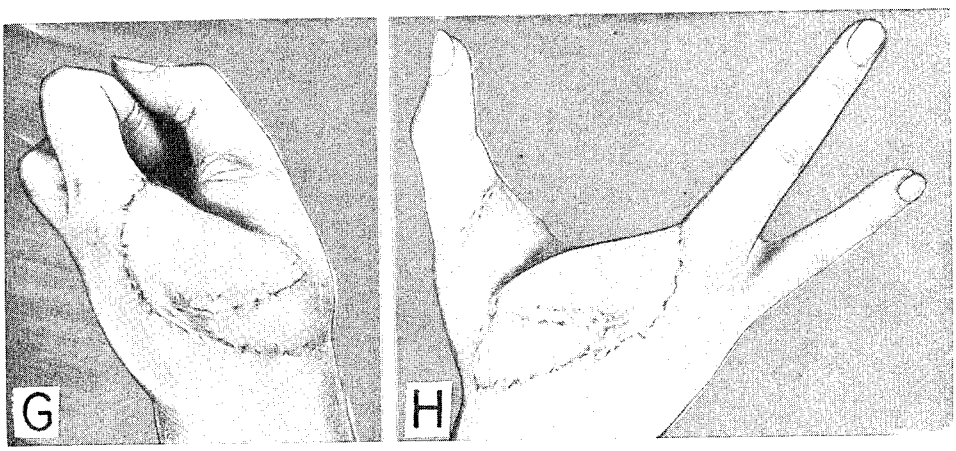




*Figure 142*--Continued.

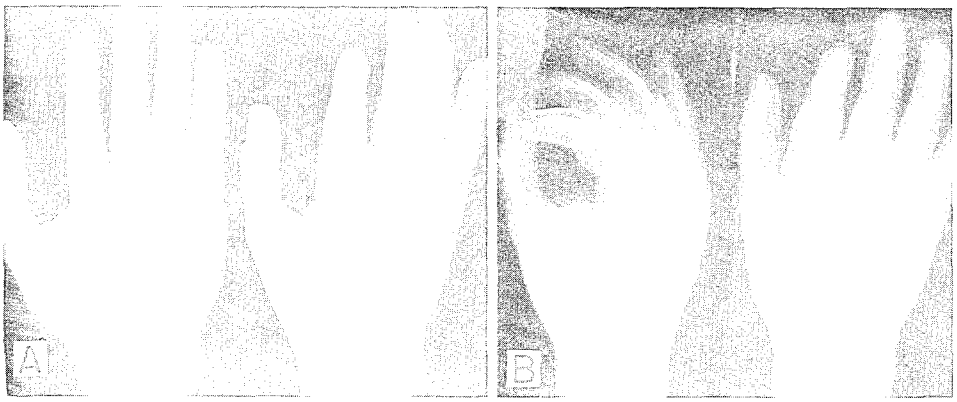



*Figure 143. Iliac bone grafts with removable fixation wires. A. Preoperative roentgenograms. B. Postoperative roentgenograms.*

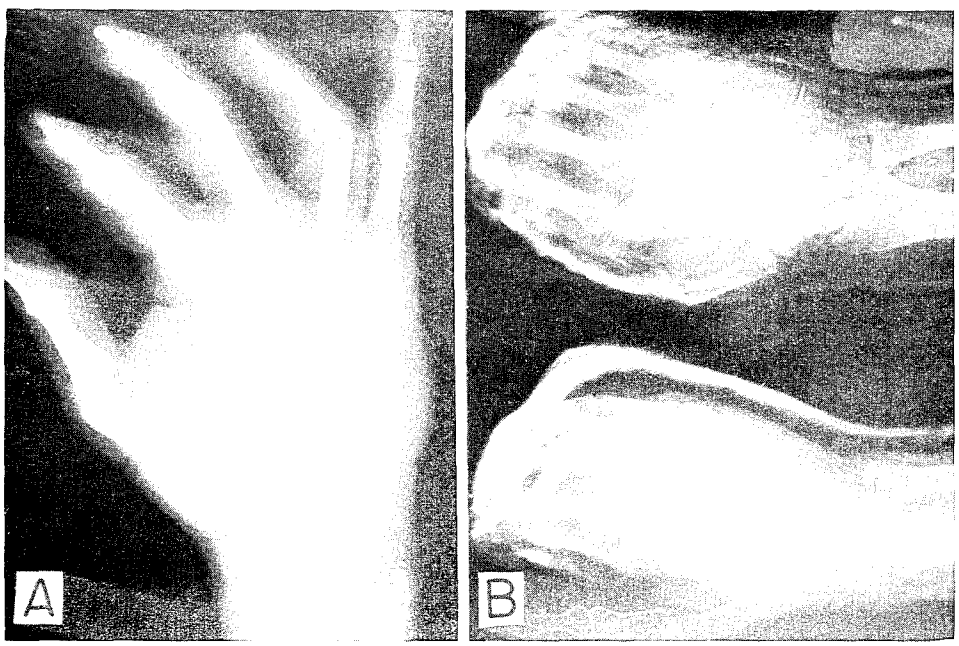



*Figure 144. Ulnar peg graft with transverse fixation wires to restore length and stability to metacarpal of ring finger. A. Preoperative roentgenograms. B. Postoperative roentgenograms.*

This procedure accomplished removal of the scar, shortened the period of disability, and permitted early mobilization of the rest of the hand.

If the long or the ring finger was badly damaged, the affected ray was completely excised and the little or the index finger transplanted. By this

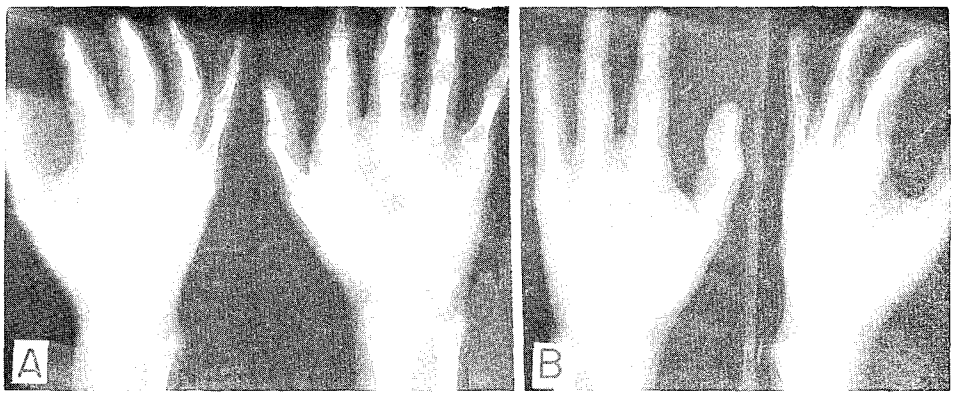



*Figure 145. Fillet of middle finger, transplantation of index finger, and correction of bony alinement with peg grafts. A. Preoperative roentgenograms. B. Postoperative roentgenograms.*

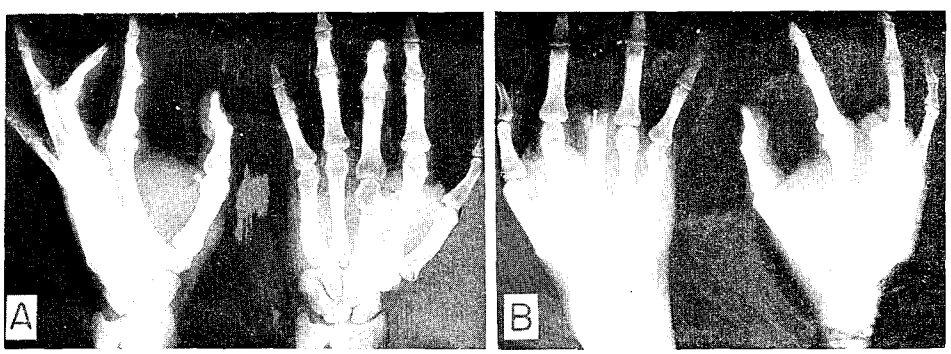



*Figure 146. Fillet of middle finger (Howard technique—recession of phalanx into a metacarpal) to maintain carpal arch and prevent crossing of fingers. A. Preoperative roentgenograms. B. Postoperative roentgenograms.*

technique a three-fingered hand was secured which was functional and also desirable from the cosmetic standpoint.

If metacarpals of the long or the ring finger were severely damaged, the proximal phalanx of the finger was used to supply the metacarpal shaft and head. The distal two segments of the finger were filleted and the proximal phalanx telescoped into the hand to restore the metacarpal head and metacarpal arch. This procedure prevented rotation and crossing of the fingers on flexion (Fig. 146).

Capsulotomy and arthroplasty of the metacarpophalangeal joints accomplished restoration of between 50 and 70 degrees of motion in most cases. When ligamentous contracture of injured joints resulted in stiffness on extension, restoration of flexion greatly improved function of the digits.

Capsulotomy or arthroplasty on the interphalangeal joints was performed only for deformities in which the finger was held in complete extension or in which these joints were displaced laterally. As a rule, 10 to 20 degrees of motion could be gained by capsulotomy. When arthroplasty was performed care had to be exercised not to remove too much bone, a flail joint might result.

## NERVE REPAIR

When nerve suture was performed early the proportion of cases in which nerve function returned was much higher than when this procedure was delayed. When infection was prevented or minimized good results in respect to both motor and sensory nerve elements were obtained. Patients whose wounds could be closed early overseas and who were returned promptly to the Zone of Interior could be treated by complete excision of the scar and early secondary suture of the nerve ends, with excellent approximation.

General use of flexion of adjacent joints to overcome nerve defects made suture possible in World War II in many injuries which would formerly have been considered irreparable. In fact, several patients were received at the hand center at Dibble General Hospital with nerve damage in the hand designated as irreparable. Nerve defects of as much as 5¼ inches were, however, bridged by direct suture. Other traumatic gaps were lessened by using traction sutures of stainless steel wire applied to the neuromatous bulb and drawn through the skin.

Volar digital nerves were sutured even at the distal flexion crease. This procedure afforded considerable improvement in the function of the thumb and index finger in patients in whom loss of sensation on tactile surfaces had caused considerable disability. A number were treated with free nerve grafts from the sural nerve, with good return of function. Nerve grafts were used on both motor and sensory fibers. To permit satisfactory circulation and nutrition they were sutured as cable grafts.

Large defects in the median and ulnar nerves were bridged under tubed pedicles in the forearm, wrist, and hand, with return of sensation to the digits. Nerve suture was accomplished with fine black silk (No. 7–0) on atraumatic needles.

To prevent the atrophy and deformity which were the inevitable results of delay, repair of motor nerves was given priority over plastic and orthopedic procedures. In 12 cases treated by deep ulnar motor nerve suture, great improvement of function in the palm of the hand resulted.

When hand injuries were received from neurosurgical centers for tendon repair following neurosurgery, contractures from longitudinal surgical scars often had to be broken up by Z-plasty, to prevent further contractures. Tantalum foil was also removed from about the nerve suture sites whenever it was present, always with improvement in sensory and motor function.

In the later months of the war a large number of patients with disabled hands were received from neurosurgical and vascular centers. Their injuries showed a lack of attention to splinting designed to maintain the position of function or to avoid overstretching of paralyzed muscles. Records in many of these cases indicated that no intensive effort had been made to use occupational therapy. In many instances these patients were received too late for any type of hand surgery to salvage the maximum degree of function. They illustrated the concept that better function and less permanent disability could be accomplished by careful evaluation of the problem of reconstruction of crippled hands by a surgeon interested in function rather than by one interested in a specific specialty.

## REPAIR OF TENDONS

In the repair of injured tendons the principles developed by Bunnell and his associates were generally practiced. It was learned promptly that it was most important to mobilize the joints before undertaking tendon surgery. A number of patients were observed in whom tendon suture or grafts had been attempted in stiff fingers, with very poor results. A complete passive range of motion was always achieved before reparative tendon surgery was undertaken.

A greater range of motion was secured by selection of proper sites for incisions, as described by Bunnell. Incisions across flexor creases were avoided and Z-plastic ones were used for the contracting scars which had resulted from combat wounds or from previous thoughtlessly placed incisions.

An important point in technique in tendon surgery was the complete excision of scar tissue, since scar breeds scar. When the scar was precisely and completely excised, a minimal amount of residual deformity resulted. It is obvious that in a bed free from scar tissue a repaired tendon will glide more freely, a bone graft will heal more rapidly, and greater nerve function can be secured.

Minimal trauma during surgery was another important factor in tendon suture.

According to the Bunnell technique removable stainless steel wire sutures were used exclusively with highly satisfactory results.

The frequent use of tendon grafts greatly improved the end results and in many seemingly hopeless cases useful ranges of motion were restored to digits by such grafts. Best results from both sutures and grafts were secured when suture was done in the palm or forearm. Tendon grafts were supplied from the lower third of the forearm to the center of the palm, or from the center of the palm to the distal joints of the fingers. Within the canal of the fingers or within the carpal canal at the wrist tendon sutures were avoided. Since the tendon must glide through the finger like a piston in a cylinder it was obvious that adhesions formed more readily in these narrow channels, whereas in the palm and forearm a greater range of sliding was possible. Better results

secured in the latter arms were thus readily explained. Generous use of fascia to prevent readherence of freed tendon to scars, or to fracture sites, improved the range of motion in many digits.

To restore balance and useful function to the hand tendon transplantation was performed in several different ways:

1. The flexors of the wrist, to restore extension to the thumb and digits in radial nerve injuries or in instances when there had been extensive loss of extensor muscle tissue.

2. In the flat hand, resulting from paralysis and atrophy of the opponens pollicis muscle in injuries of the median nerve, from direct trauma to this muscle with resulting loss of tissue and function, and from vascular damage with atrophy of the intrinsic muscles of the hand. Restoration of the position of opposition of the thumb was accomplished by either osteotomy on the first metacarpal or a pulley tendon transplant by the Bunnell technique: The short extensor of the thumb is brought subcutaneously across the palm of the hand in the direction of the pisiform bone, then looped about the flexor carpi ulnaris and attached to a motor muscle in the forearm.

3. The flexor sublimis muscle or the extensor proprius of the index finger to restore the action of damaged or paralyzed intrinsic muscles. The extensor indicis proprius was transplanted to replace the first interosseous muscle to abduct the index finger and thus provide a very useful function.

4. Where there was an extensive loss of the intrinsic muscles the result of perforating wounds of the hand or of atrophy from damage to the median and ulnar nerves. The procedure was as follows: The flexor sublimis tendons were detached at the middle finger joint. Their two attachments were split and transplanted through the palm of the hand down the lumbrical canal to the dorsum of the fingers, where they were imbricated into the extensor apparatus, usually of the same side (radial or ulnar) of the two adjacent fingers. By splitting the tendon into its two segments and placing them through the hand onto the dosum of the adjacent fingers, abduction or adduction was achieved for these fingers, the two distal joints were extended, the proximal joints flexed, and the disability in the injured hand, was considerably reduced.

Injuries of the brachial artery usually resulted in deformity of the hand, marked adduction of the thumb and stiffness in the finger joints. Considerable improvement could be effected by stripping the intrinsic muscles from the metacarpals and adductors of the thumb to permit a position of grasp in the fingers and spread of the web of the thumb.

## AMPUTATION

When digits had to be amputated, the operation was done so as to preserve as much length as possible. If the finger was stiff and in the way because of its length, it was shortened. To maintain breadth of palm and preserve a

stronger hand the index finger was generally amputated through the metacarpophalangeal joint. Sometimes for cosmetic reasons it was done high in the metacarpal. When operation was performed at this site, the thumb web was increased, the metacarpal stump which was sometimes in the way was removed, the wrist joint did not require opening, and preservation of the attachment of the extensor carpi radialis tendon was maintained.

Extensive damage to more than two structures, such as the skin and a nerve, the skin and a tendon, or a bone and a tendon, generally required amputation of the fingers. In such cases reconstruction involved so many structures, and the resulting improvement was so slight, that the multiple procedures and prolonged hospitalization required were not warranted. Here, as in all reconstructive surgery of the hand, it was necessary to weigh the possible restoration of function against these factors.

Transplantation of an index finger to replace an amputated thumb was carried out on strict indications: The injury had to be on the major hand, and the patient had to have sufficient intelligence to appreciate both the usefulness and the limitations of the transplanted digit. The operation was accomplished by the use of a tubed pedicle and a bone graft. The restored thumb usually had satisfactory sensation and motion.

Painful, tender stumps were effectively treated by the use of visor flaps (Fig. 147), skin grafting the dorsal denudation.

## ADJUNCT MEASURES

Physical and occupational therapy were important factors in rehabilitation of injured hands. Physical therapy was used chiefly after the early institution of gentle passive motion, supervised and graduated voluntary motion, and special exercises, in which the patient was carefully instructed by the physical therapist.

After physical therapy had been carried out for several weeks occupational therapy was begun. It was always more profitable than physical therapy because it required voluntary exercise and produced useful work, in which the patient was interested. Patients were invariably willing to work harder and for longer periods of time for the satisfaction of producing something and of improving the function of the injured hand. In instances of serious injury and deformity, occupational therapy was always of greatest value when it was carried over into vocational rehabilitation and industry.

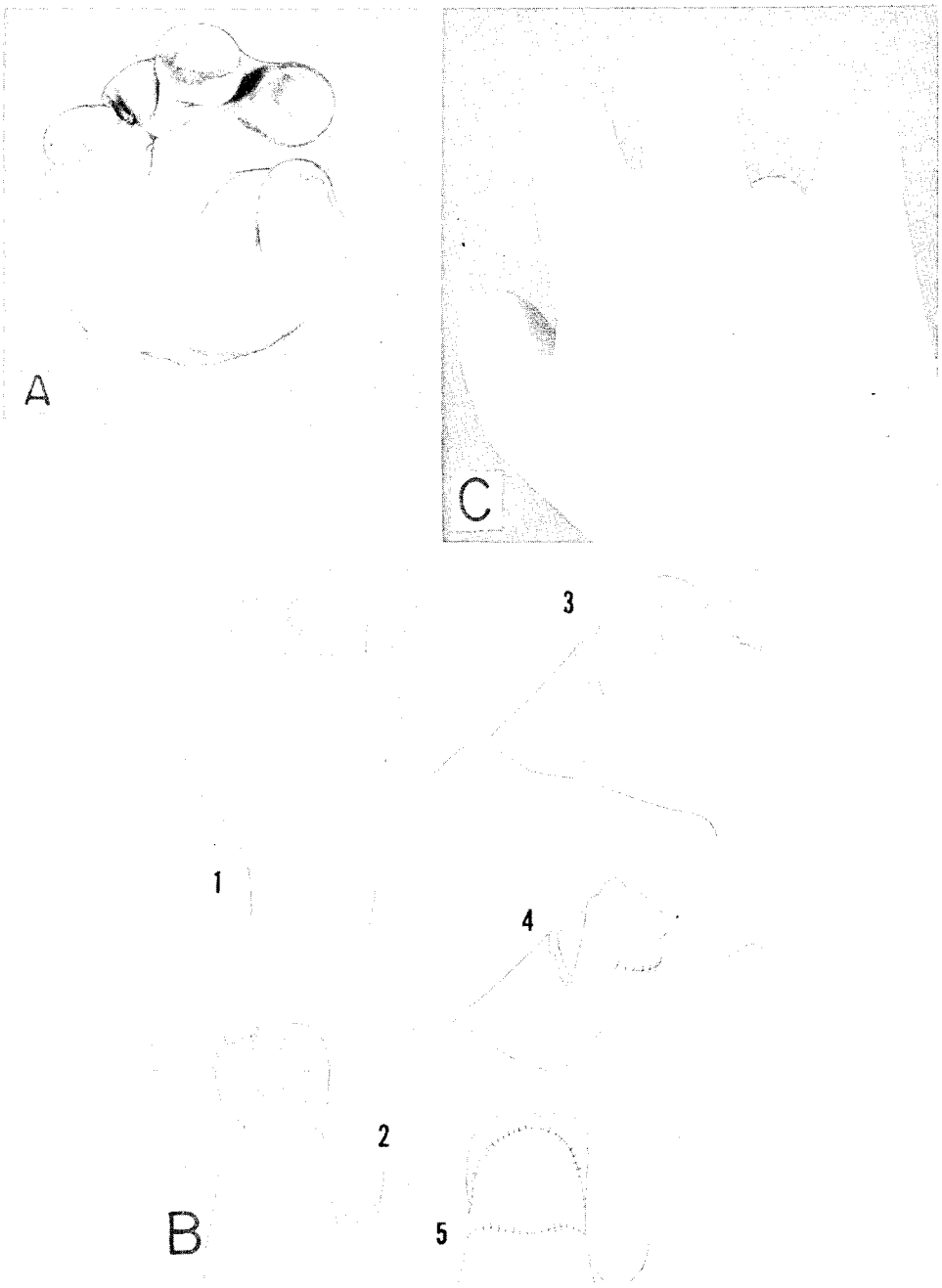



*Figure 147. Visor flap operation for painful, tender stumps. A. Amputated stumps, following injury by land mine, with thin, tender scars. B. Technique of visor flap shift and insertion of thick split graft. C. End result. Patient can now exert pressure on table without pain.*

CHAPTER XI

# Hand Surgery at Northington General Hospital

*Arthur J. Barsky, M. D.**

At a clinical meeting early in November 1944, the suggestion was made that a board for hand surgery be set up in the hospital without delay and that it be patterned along the same lines as a well-established tumor board. It was to be composed of an orthopedic, a plastic, and a neurosurgeon. It was to function as a unit and (1) to examine all hand injuries that required the attention of more than one specialist; (2) to diagnose the injury in terms of tissue loss and functional involvement; (3) to decide what procedures were to be carried out; (4) to prescribe the proper sequence of all procedures, and (5) to recommend the ultimate disposition of the patient.

The board was organized with chiefs of orthopedic, plastic, and neurosurgical sections as members, and the chief of the surgical service as chairman. The number of patients and the pressure of work prevented the board from fulfilling its function to the fullest extent; it became an administrative body rather than a board for planning treatment of the injured hand. Patients were designated as "joint" cases and, as so often happens where dual responsibility exists, primary responsibility was assumed by no one, and the treatment of the injured hand was sometimes delayed.

In February 1945, the Civilian Consultant for Hand Surgery visited Northington General Hospital, examined many patients, and outlined their treatment. It became clear that if patients with hand injuries were to have the best results, responsibility for their care should be placed with a single group. Therefore, in the first week of March 1945, a separate unit, the plastic hand section, was organized. It was headed by a plastic surgeon, with an orthopedic surgeon as assistant chief. This team made a joint survey of all the patients with hand injuries in the hospital at that time, outlined treatment and carried it out. Within a short time it was necessary to add another surgeon to the section so that there might be three operating teams to care for the patients. Each team consisted of an operating surgeon with a ward officer as assistant.

## FACILITIES

The hand section occupied 5 complete wards and part of 2 others; it maintained an average bed capacity of about 250. Highest patient census

*Plastic Surgeon to the Mount Sinai, Beth Israel, Bronx, and Morrisania City Hospitals, New York. Formerly Lt. Colonel, MC, AUS.

was 676. By using the reconditioning facilities, about 125 patients not requiring bed treatment could be kept in the hospital where they were available for follow-up and constant checking. In addition, approximately 125 to 250 patients could be kept on convalescent furlough between operative stages. If a patient might benefit by it, a work furlough was granted.

## QUALIFICATIONS AND TRAINING OF PERSONNEL

Chief of the hand section was a plastic surgeon with considerable experience in hand surgery; the assistant chief was an orthopedic surgeon, and the third senior surgeon had had considerable experience in peripheral nerve surgery. They were certified by the American Boards of Plastic and Orthopaedic Surgery. In selecting ward officers surgeons were chosen who had an interest in hand surgery and a background of general surgery. Instruction and training were constantly carried out during ward rounds and at the operating table.

## ADMISSION

Patients whose principal injury involved the hand were admitted directly to one of the wards on the hand section; those whose hand injuries were of secondary importance were sent to the section which was to treat the primary injury. These latter patients were sent to the hand section for consultation as soon as possible, and if prompt treatment were required (corrective splinting, or surgery) it was started without delay while the patient was undergoing treatment for another condition.

Upon entry to a hand ward, the patient was given a complete physical examination. When indicated, consultations with other sections were arranged, and the general condition of the patient thoroughly surveyed before treatment was undertaken. All new patients were presented at the hand section rounds; all members of the hand section were required to be present at that time. The operating surgeon described the patient's condition and the treatment contemplated. The group discussed thoroughly all aspects of the case and decided upon the operative plan.

## NUMBER OF OPERATIONS

Some 917 operations were performed at Northington General Hospital Hand Center between 1 March, the activation date of the hand section, and 30 November 1945* (Table 13). Virtually no fresh injuries were received, fresh fractures were uncommon, and only a few fresh lacerations were observed.

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*The data on which this chapter is based were compiled by the author for the period set out. Statistics for the entire year are available in the 1945 Annual Report of Northington General Hospital. HD: 319.1-2.—Ed.

TABLE 13. OPERATIONS PERFORMED AT NORTHINGTON GENERAL HOSPITAL HAND CENTER, 1 MARCH TO 30 NOVEMBER 1945

| Type | Number | Type | Number |
|---|---|---|---|
| Amputations | 57 | Osteotomy | 14 |
| Arthrodesis | 4 | Preparation of tube pedicle | 135 |
| Arthroplasty | 28 | Removal of foreign body | 10 |
| Biopsy | 4 | Resection of head of ulna | 1 |
| Bone graft | 36 | Revision of scar | 106 |
| Capsulotomy | 26 | Separation of flap | 9 |
| Direct flap | 20 | Sequestrectomy | 15 |
| Excision of scar | 26 | Skin flap to hand | 281 |
| Excision of bony spur | 8 | Tendon graft | 24 |
| Free skin graft | 38 | Tendon repair | 53 |
| Injection of keloid | 1 | | |
| Nerve suture repair in hand and at wrist | 21 | Total | 917 |

## RECONSTRUCTION

### Examination

The hand was examined thoroughly. For this purpose a simple chart or diagram expedited notations. The opposite hand, if normal, was used as a basis for comparison; the whole arm was inspected, and the general trophic condition noted. Dry, shiny skin and tapering fingertips indicated loss of nervous sensation. The posture, or the way fingers and hand were held, was also noted, and general strength ascertained.

A neurologic examination was made and the areas in question tested for light and coarse touch, analgesia, paresthesia, hypo- and hypersensitiveness.

Details secured were:

1. The amount of movement of the fingers, voluntary and passive motion in each joint. Amount of movement, flexion, or extension was expressed as a fraction $V/P$, with $V$ the range or arc of voluntary motion, and $P$ the range of passive motion. For example, a hypothetical case might be expressed by the fraction $\frac{V\ 160\ \text{to}\ 120.}{P\ 180\ \text{to}\ 100}$ These fractions were written on the chart opposite the joint in question, recording flexion as well as extension.

2. The movement of the entire finger. This could be noted on the chart by making an "X" where the fingertip would normally touch the palm and measuring the distance by which the finger failed to reach the palm (for example, minus 2 cm.).

3. Lack of extension of the finger. A straight edge was placed along the dorsum of the hand and the distance measured by which the finger failed to extend fully.

4. Particular data on the thumb. Measurements of its extension, flexion, adduction, and opposition were taken. Its position in relation to the plane of the palm was noted. Extension was tested by placing the palms together and comparing the thumb under consideration with that of the normal side, noting the difference between the range of motion of the two. Adduction was tested by bringing the thumb along the radial side of the hand in the palmar plane. Opposition could be determined in two ways. One was the greatest distance the palmar surface of the tip of the thumb attained when it was opposite the base of the middle finger. If the thumb had limited motion, the measurement could be made opposite the base of the index finger. The second measurement was the angle formed by the thumbnail and the palm when the thumb was in opposition. Since the nail is parallel to the palm in this position, the normal angle is zero; but when the thumb is at the side of the hand the angle is 90 degrees.

5. Abduction of the fingers. This was tested by determining the spread of the fingers and comparing it with that of the normal side.

## Diagnosis

Diagnosis of the war injury or defect was precisely determined, for diagnosis was the foundation of surgical treatment. At the outset the possibility of any central cause, or any cause higher up than the hand itself had to be ruled out, bearing in mind that contractures of the hand are often due not to one cause but to several and, therefore, the condition could not be corrected unless all causes were diagnosed. Flexion contractures were encountered most frequently; probably the most common cause was damage to the skin itself, along with flexor tendon damage.

After thorough examination had been completed and charted, data were reviewed. If voluntary motion was affected, the muscle-tendon apparatus or innervation was at fault. If motion was passively limited, too, causation might lie in the joint itself, or be due to a contracture of the flexor or extensor apparatus which, in turn, was contracted or adherent. If the patient was not able to move the joint voluntarily, but the examiner could move it passively, the tendon was not acting. If limitation of passive and voluntary activity was about equal, cause of the disturbance might be either in the joint or in the opposing tissues. If passive motion had a normal range but voluntary motion was limited, it was obvious that neither the joint nor the opposing tissues were at fault. If both passive and voluntary motion were somewhat limited, both the joints and the opposing muscle-tendon apparatus might be contributing causes, though the major cause was the lack of muscle-tendon apparatus function.

In determining whether adherence was on the back of the hand or in the wrist or forearm, dorsiflexion of the wrist permitted the fingers to extend when adherence was above the wrist; if adherence was in the back of the hand itself,

dorsiflexion of the wrist did not effect extension. When it was found that neither passive nor voluntary extension of the fingers could be carried out but the fingers could be voluntarily extended when the wrist was volar flexed, the flexor muscle-tendon apparatus was most probably at fault; it might be either too short or adherent above the wrist (checkrein action). If a finger could not be extended either voluntarily or passively until the proximal finger joints were flexed, an adhesion proximal to the finger joint, that is, in the palm, was indicated. When it was impossible to extend the fingers by voluntary or passive motion, regardless of position of the proximal joint and wrist, the condition signified either involvement of the finger joints or adhesion of the flexor tendons within the finger itself.

Damage to the intrinsic muscle-tendon apparatus was manifested when voluntary extension of a digit was good at the proximal joint but poor at the distal two. An incomplete voluntary flexion of the fingers, associated with complete passive motion, pointed to a nonfunctioning flexor-tendon apparatus. In such a hand, action of the intrinsic muscles, if they too had not been damaged, made it possible to flex the proximal finger joint.

Complete absence of voluntary flexion of the distal two finger joints displayed an involvement of the flexor-tendon apparatus. In the presence of adhesions located proximal to the proximal finger joints, that is, adhesions in the palm or in the forearm, passive flexion of the proximal finger joints permitted the fingers to be extended, since flexion released the checkrein action of the adherent tendons. If it were noted that flexion of the proximal joint did not permit extension of the distal two finger joints, adhesions were within the finger itself (assuming that the intrinsic muscles were intact). When adhesions in the forearm were released by flexing either the wrist or the proximal finger joints, the fingers could be extended. *As a general rule the existence of a contracture or adherence proximal to a joint may be demonstrated by relieving tension (the examiner flexes the joint) and noting voluntary joint action of those joints distal to the one that has been flexed.*

When a patient attempted to flex the fingers completely, yet the tips touched only the *distal* portion of the palm or the bases of the fingers themselves, and could not be made to contact the proximal portion of the palm, the proximal finger joints or the intrinsic muscles of the hand were at fault. If the difficulty was centered in the joints themselves, the most common cause of joint disability was contracture of the collateral ligaments, which, in turn, might be due to splinting of the fingers for a prolonged time with the proximal joints extended, or to infection. When the fingertips on flexing contacted the *proximal* portion of the palm but not the region in the distal crease, the cause was either joint involvement of the middle or distal joints, or limitation of motion of the flexor tendons.

When a finger had lost adduction and abduction, the interossei and lumbrical muscles were at fault unless there was scar formation along the side of

the base of the finger. Adduction of the thumb was often due to contracture of the tissue between the first two metacarpals, the result of infection or injury. Such a contracture was not infrequently found when the patient had sustained an injury to the large vessels of the arm, requiring ligation. When the thumb had lost voluntary opposition but passive motion could be demonstrated, median nerve injury was indicated. If this was the only damage in the hand, the motor thenar nerve had been damaged, affecting the opponens and the flexor brevis pollicis. When the thumb could not assume a position of opposition either voluntarily or passively, scar contracture between the first two metacarpals might be the cause, or it could be checkrein action from adhesion of the long extensor of the thumb. Other possible causes were ankylosis of the carpometacarpal joint, and rigidity due to the flat splinting of the hand.

Amplitude of motion of the flexor tendons of all fingers might be interfered with if the flexor tendon of one damaged finger was adherent.

When the distal finger joint could be flexed passively but not voluntarily, and the proximal and middle joints could be flexed voluntarily, the condition was due to damage to the profundus tendon—either severance or adherence of the profundus to the sublimis. If the profundus tendon had been severed, there was no voluntary motion whatsoever in the distal joint; whereas if there was adherence between the two tendons there might be very slight voluntary flexion of the distal joint.

## Preoperative Preparation

The night before operation, the fingernails were cut, the forearm and hand were shaved, then washed with soap and water. In the operating room the hand was again thoroughly scrubbed with soap and water, laved with alcohol, and one of the stainless skin antiseptics applied.

## Anesthesia

Ether was the anesthesia of choice, with thiopental sodium induction, but for short operations, thiopental sodium and oxygen was preferred. In preparing abdominal flaps in conjunction with local anesthesia on the hand spinal anesthesia was often used. For minor procedures local anesthesia was occasionally employed No adrenalin was added to procaine hydrochloride when infiltrated into fingers. Injection was made very slowly and gently.

## Instruments and Equipment

Operations were performed in a bloodless field provided by a pneumatic tourniquet; operating-room personnel were carefully instructed in its proper application. The anesthetist called time in 15-minute intervals. At the end

of an hour, the tourniquet was released to permit restoration of circulation. After a 5- or 10-minute interval it was reapplied.

Draping was simplified, and the number of drapes reduced by using a very large sheet with a circular opening and drawstring for the arm.

A small, stout, metal-covered table approximately 15 inches wide, 24 inches long, and 36 inches high was used. The table had a crosspiece for a footrest. Some of the special instruments used are shown in Figures 148 through 151.

## Surface Anatomy and Incisions

Surface covering of the hand is unique and admirably suited to its purpose. The palmar area is covered by thick, tough skin, with a heavy fat pad beneath it. Palmar skin is inelastic, but a number of creases and folds allow movements of the fingers; it does not lend itself well to flaps. The skin of the dorsum is thin and flexible; its subcutaneous tissue is much thinner than that of the palmar surface. Dorsal skin has creases also, particularly over the joints, to allow them to move freely. The skin of the dorsum can be used for flaps. Pulps of the thumb and fingers, especially the first two, are richly supplied with touch corpuscles which are lacking in most other skin areas of the body. Thus, if the

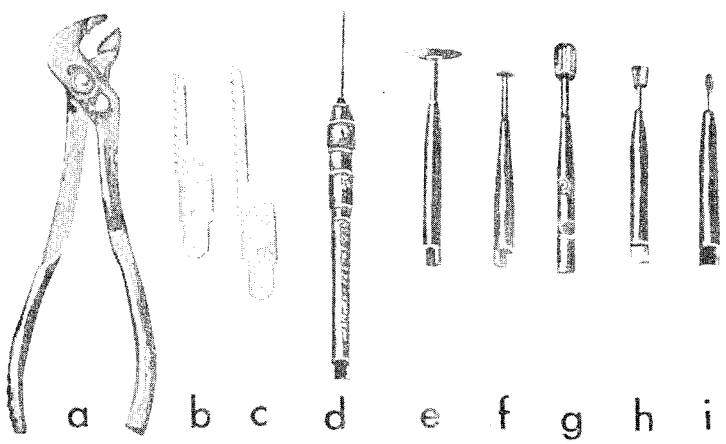



*Figure 148. Instruments devised or converted to use at Northington General Hospital. a. Mechanic's ignition pliers, for holding metacarpal bones. b and c. Saw blades for reciprocating type of saw (Cayo). d. Small pin vise used to insert Kirschner wires; when held in the power saw wires could be placed exactly and efficiently. e and f. Small circular saw blades. g and h. Rotary files for smoothing bone and cutting grooves. i. Small drill.*

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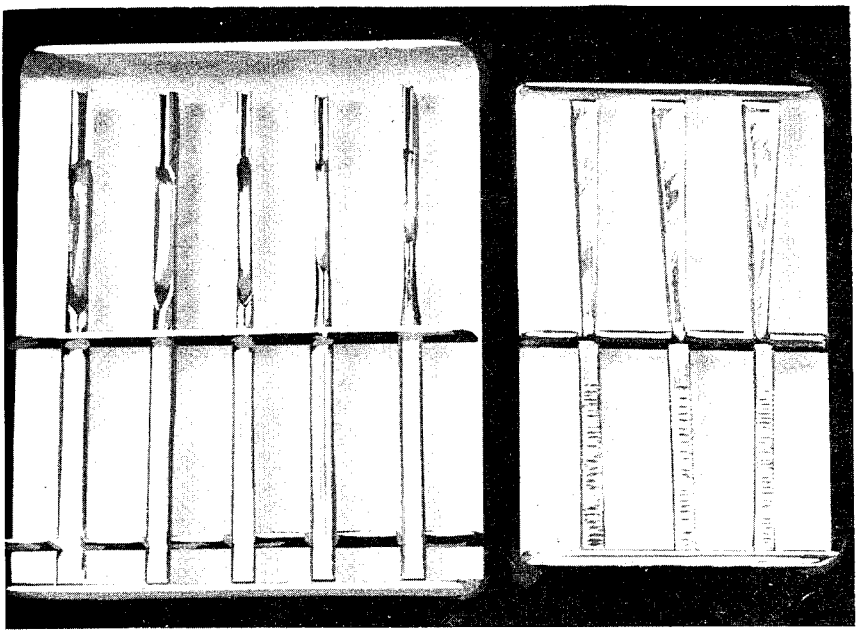


*Figure 149. Metal racks for holding sharp instruments at the operating table and during sterilization. Designed to prevent damage to sharp edges.*

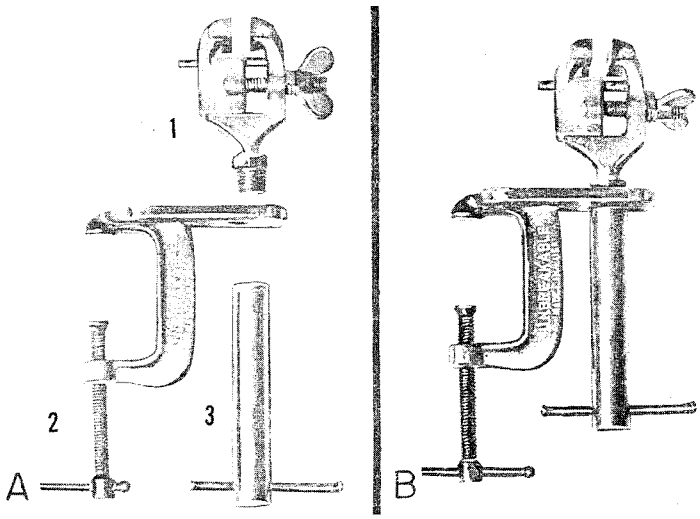



*Figure 150. Bone vise. A. Parts of vise. B. Instrument assembled. Vise can be clamped to a table or, if only parts 1 and 2 are used, can be held in the hand.*

tip of a finger is replaced by a flap from a distant area, fine perception can never develop.

Movements of the hand are so well coordinated and delicately balanced that function is severely hampered if the surface is replaced by inelastic or unstable scar. Whenever possible, therefore, incisions should parallel and preferably coincide with the normal flexion creases. In the palm these incisions often permit adequate exposure. In the finger, although much work can be done through small transverse incisions in the flexor creases, it is frequently necessary to employ longitudinal ones. These should always be midlateral, avoiding injury to the digital nerves. Through lateral incisions the most extensive dissection may be performed. It is inadvisable to connect a horizontal with a vertical line in the finger, since the right-angle portion so formed often undergoes necrosis, ruining whatever plastic reconstructive work has been performed beneath the necessarily intact skin. When skin has been excised, lines of graft suture should also be planned in accordance with the above principles.

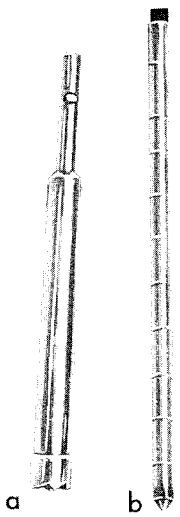



*Figure 151. a. Peg former. When the bone graft is held in a vise, the peg can be cut quickly with cutter. b. End-cutting drill with smooth sides for insertion through small incisions in soft tissue without causing damage. The drill is marked in centimeters so that the operator can tell exactly how far it has been inserted.*

## Resurfacing

In resurfacing, the graft or flap should be ample, and in planning the pattern the surgeon should be guided by the size of the normal hand. An injured or burned hand is deceptive; it is always smaller than the uninjured one. The importance of adequate covering cannot be overemphasized, and in contem-

plating any reconstruction, superficial or deep, the surface must first be replaced by an adequate, stable covering. A surgeon should never be tempted to carry out operations on deeper structures through scarred, unstable surface.

In instances of gunshot wounds where subcutaneous tissue as well as skin has been damaged, or where surgery on the deeper structures (such as tendons, nerves, or bones) might be expected, flaps rather than free grafts are usually used, except that flaps on the palmar surface should be avoided if a free graft

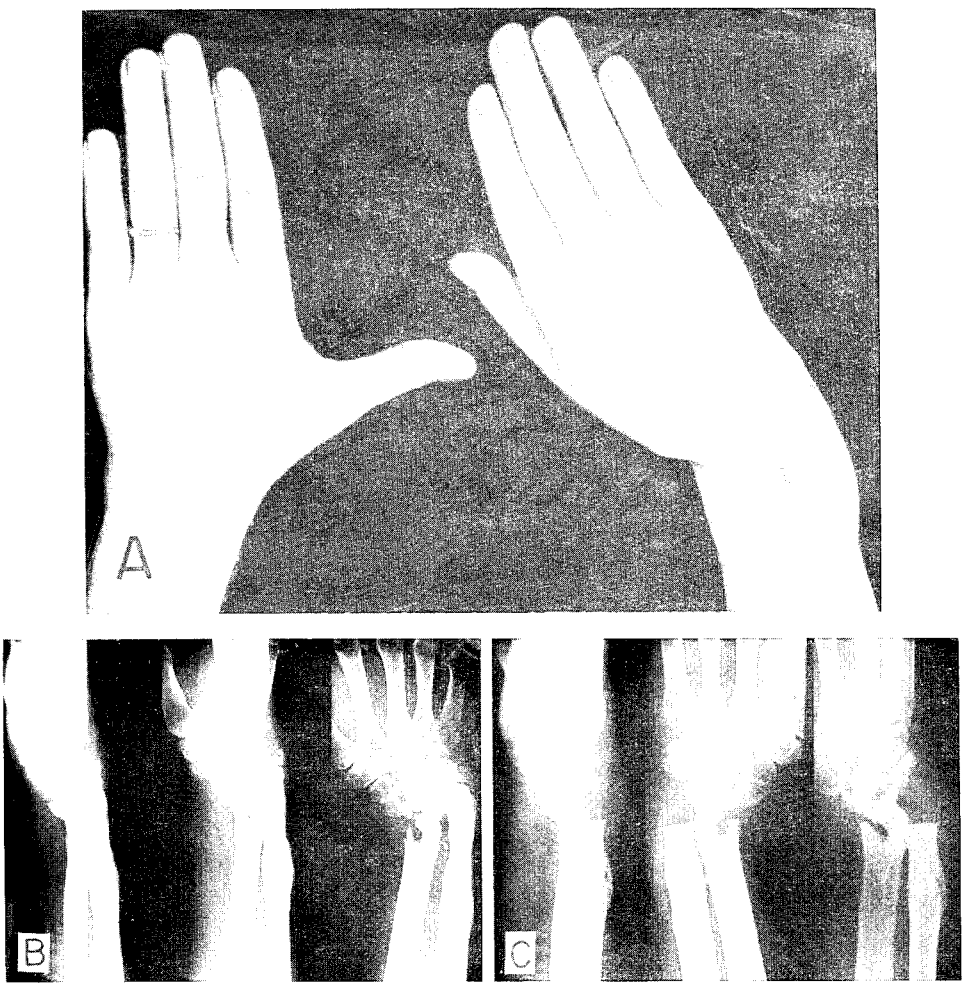



*Figure 152. A. Flap applied to the dorsum of the wrist before surgery of the deeper structures could be performed. B. Preoperative roentgenogram. Loss of the distal portion of the radius produced radial deviation of the hand. C. Postoperative roentgenogram, showing correction by means of resection of the head of the ulna.*

will suffice. Flaps supply tissue which closes and heals over any deep repair (Fig. 152). No "open" flaps were used at Northington General Hospital.

A tube pedicle prepared at one operation and migrated at a second might be used (Fig. 153), and although this involved two operative procedures, an open pedicle was avoided. The tube pedicle had excellent circulation, was well adapted to fit the irregular contour of the hand, particularly that of the fingers, and its long, flexible pedicle facilitated manipulation in the difficult hand region. Having to open the tube for adjustment and dealing with scarring of the tubing itself, however, may be such a chore and be so fraught with trouble that many surgeons would prefer to avoid tubed or double pedicle or delayed flaps whenever possible.

Other types of flaps employed at Northington General Hospital were a direct flap with pedicle tubed and the donor area closed, and a flap lined with a free graft which covered the donor area as well. In some instances a flap was used in which the raw surface of the pedicle was covered with a small hinge flap reflected from the area of defect. The direct flap (Fig. 154) has many advantages; it requires only one operative stage; it can be designed most accurately; and can be on or off the hand in less time than that required for preparation of the tubed or delayed flap. With the hundreds of flaps that had to be done during the war the saving in patient months of hospital stay was great. At the time the defect is created this flap can be designed, elevated, and ready for use in a few minutes time. It can be used without delay because it has a pedicle of great breadth but practically no length. If such a flap is employed, the donor area can be closed by undermining and sliding or by free grafting, avoiding a raw area.

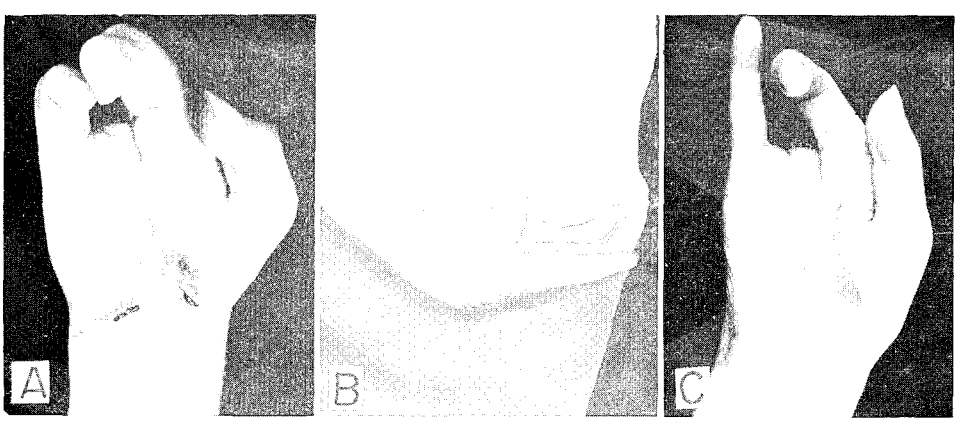



*Figure 153. A severe shrapnel injury to the wrist and hand, with loss of the middle and ring fingers. A. Preoperative condition. B. A tube pedicle migrated to the wrist. C. The flap covering the wrist, the central portion of the palm, and extending over the distal border of the hand.*



*Figure 154. A small direct flap applied to the finger. Donor area closed by undermining and sliding.*

When a flap must cover a number of fingers, it is not a good plan to split it for each finger when the flap is first migrated. Instead, small hinge flaps are reflected on the lateral surfaces of the fingers and sutured together to produce a web or "mitten" upon which the migrated flap is spread out and sutured (Figs. 155 and 156). Gauze rolls and packing are applied to the interdigital spaces to ensure good contact. Then when the pedicle is severed, the finger webs are split and draped around the fingers to cover their lateral surfaces.

Figure 157 shows the so-called "pocket flap" (actually the double pedicle flap) applied to the dorsum of the fingers. The donor area was lined with free grafts to avoid open areas.

The abdomen is an ideal donor site for flaps to the hand as it provides ample area, and postoperative immobilization is not uncomfortable. It may be preferable to use the left side of the abdomen, unless the patient has a scar there from an appendectomy.

Flaps were taken with the pedicle above or below, depending on convenience. When perforating wounds necessitated resurfacing both sides of the hand, after migrating the flap to one side, the abdominal attachment of the flap could be separated from the abdomen and migrated to the opposite side. After healing the second side, the surplus portion of the flap was scrapped. An alternate method sometimes used was to detach the pedicle at the hand after

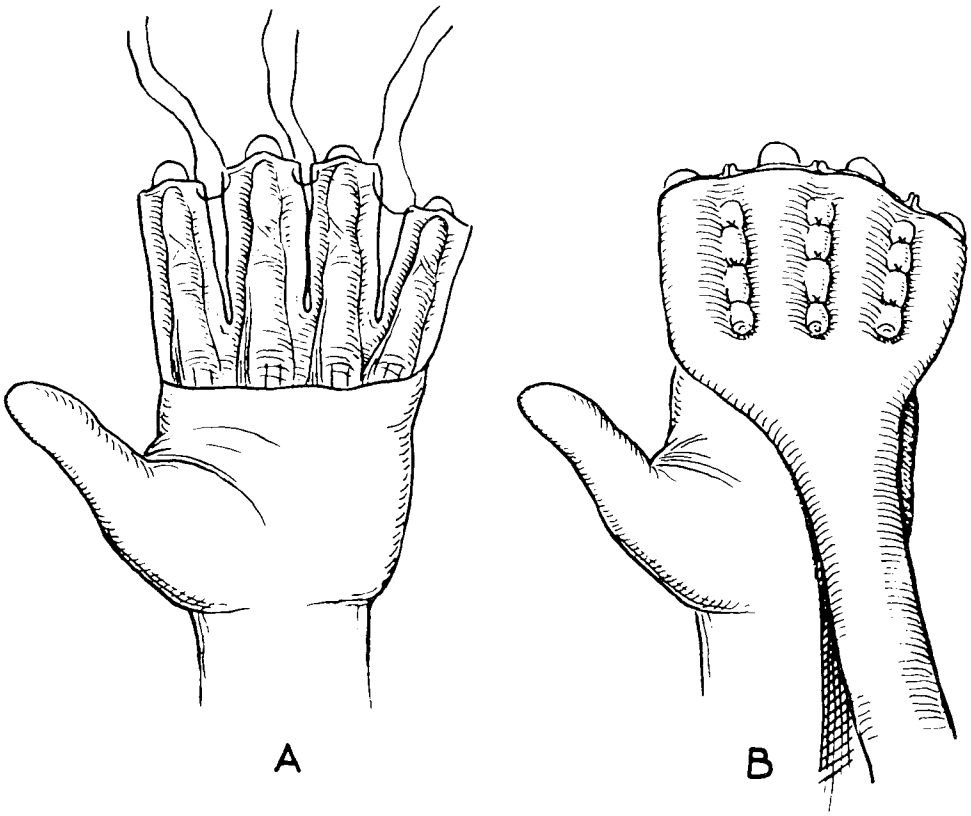



*Figure 155. Cover for palmar or dorsal surface of a number of fingers.* A. *Small flaps reflected from the sides of the fingers to provide the lining for B, one large flap applied over the entire region, avoiding any open areas. Bolsters are sutured between the fingers to maintain contact. The flap may be digitated when the pedicle is severed, or digitation may be left for a subsequent stage, if there is any question about the circulation.*

healing of the first side, leaving sufficient tissue to reach from the abdomen to the second side, then proceeding in the usual manner. The first method had the advantage of minimal restriction and immobilization of the hand.

As a general rule, pedicles were not severed until at least 3 weeks after migration. Earlier severance is possible, but more frequent complications will result (Figs. 158 and 159).

## Burns and Contractures

Recent burns involving destruction of superficial tissue were resurfaced as soon as the burn slough had separated and granulations were clean. Resurfacing by means of a free, split, or intermediate thickness graft was carried



*Figure 156. Mitten type of flap for severe burn of the dorsum of the hand. These flaps should always be generously designed.*

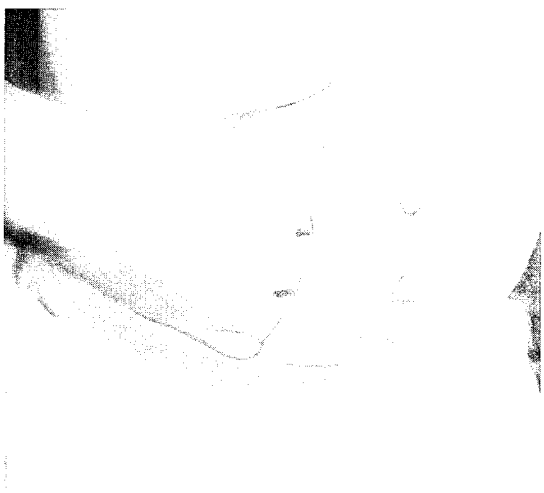


*Figure 157. So-called "pocket flap" applied to the dorsum of the three fingers. These are in reality double-pedicle flaps. The donor areas were closed at the time of operation by split grafts.*

out promptly even though it might be necessary to apply a pedicle graft at a later date. When destruction of the entire thickness of the skin occurred it was never desirable to wait for epithelization to spread. Hands are all too prone to stiffen, especially in the presence of an open wound, and when the trauma of flat splinting was added, the result was often a rigid, inflexible hand, with the rigidity frequently persisting even after resurfacing. If a splint had



*Figure 158. Flaps should never be under tension, either at the time of operation or during the postoperative period. This illustration shows slow healing and broadening of the scar because of too much tension.*

to be applied while waiting for a slough to separate from a burned hand, the hand and fingers were always immobilized in a position of function.

Fresh burns were cleaned with neutral soap and water and a fine-mesh boric acid or vaseline gauze dressing applied. Over this a bulky pressure dressing was placed and was permitted to remain for a period of about 10 to 15 days, depending upon the general condition of the patient. Meanwhile, sulfanilamide and penicillin therapy were carried out as indicated, also any supportive measures which might be necessary, such as high-protein diet, or transfusions. At the end of the appropriate interval, the first dressing was removed and the hand dressed thereafter as often as necessary until the slough separated or the area became relatively clean, so that a free split skin graft might be applied. In a few cases, where the burn was not extensive and was well localized, the area was excised and a free split skin graft used.

Infections in burns of the hand did not present any problems. Sulfanilamide and penicillin therapy, and the use of penicillin as a wet dressing, rapidly cleared infections. Phenoxetel (ethylene glycomonophenyl ether) 2.2 percent, in distilled water or combined with penicillin solution, 250 units per cubic centimeter, eliminated bacillus pyocyaneus and mixed infections. So efficient was this mixture that rarely, if ever, was a skin graft lost because of pyocyaneus infection.

In treating *healed* burns, the first requisite was diagnosis in terms of tissue involvement, then the repair was planned accordingly (Figs. 160 and 161).

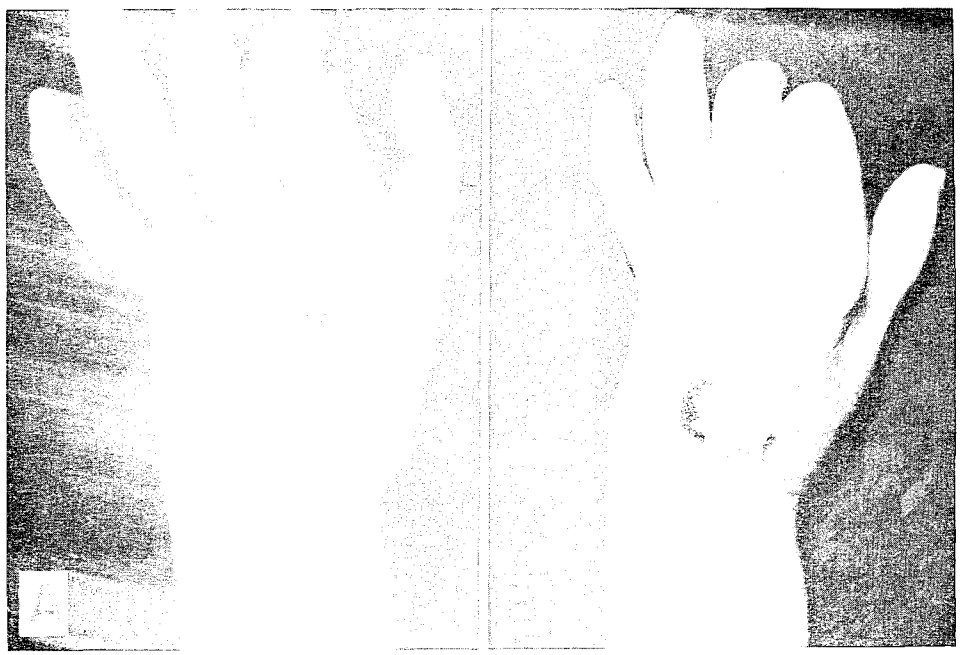


*Figure 159. Penetrating wound on the dorsum of the hand and repair. A. Preoperative view. B. Repair by an abdominal flap. The pedicle was severed on the 10th day. This resulted in a small loss of tissue. It would have been better to have permitted the pedicle to remain for 3 weeks.*

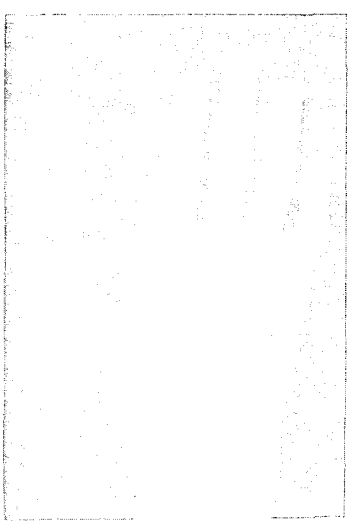


*Figure 160. A superficial healed burn of the hand. Healing is prompt and complete. The skin covering is pliable and stable. This type of healed burn requires no surgery.*

Thus, if the skin, only, had been destroyed, replacement of it alone was necessary (Figs. 162–164). If both skin and subcutaneous tissues had been destroyed, replacement of the latter tissue as well as the skin was required. This repair could be done only by means of a flap of one type or another and, except as mentioned above, flaps were not used on palmar surfaces unless entirely necessary.

Not every burn contracture could be corrected by skin grafting alone, although casual observation without roentgenogram examination might lead to the belief that joints and tendons were involved much more frequently than was actually the case (Fig. 165). In burn contractures of short duration—if the tendons had not actually been damaged—there was little tendon contracture. When contracture actually does take place it is in the muscle belly, not the tendon. Where there were no joint changes in the interphalangeal and metacarpophalangeal articulations after grafting, simple extension and stretching sufficed to correct the condition. In contractures of long duration, the muscles themselves became contracted and the joints ankylosed, even if they were not originally involved. Burn-scar contractures of the dorsum often resulted in hyperextension of the metacarpophalangeal joints and required capsulectomy



*Figure 161. Burn somewhat deeper than that shown in Figure 160. There is more scarring and pigmentation. The scar is stable and does not interfere with function. However, if the patient is a manual worker or resides in a cold climate, there may be a tendency toward cracking and in that event, the hand should be resurfaced.*

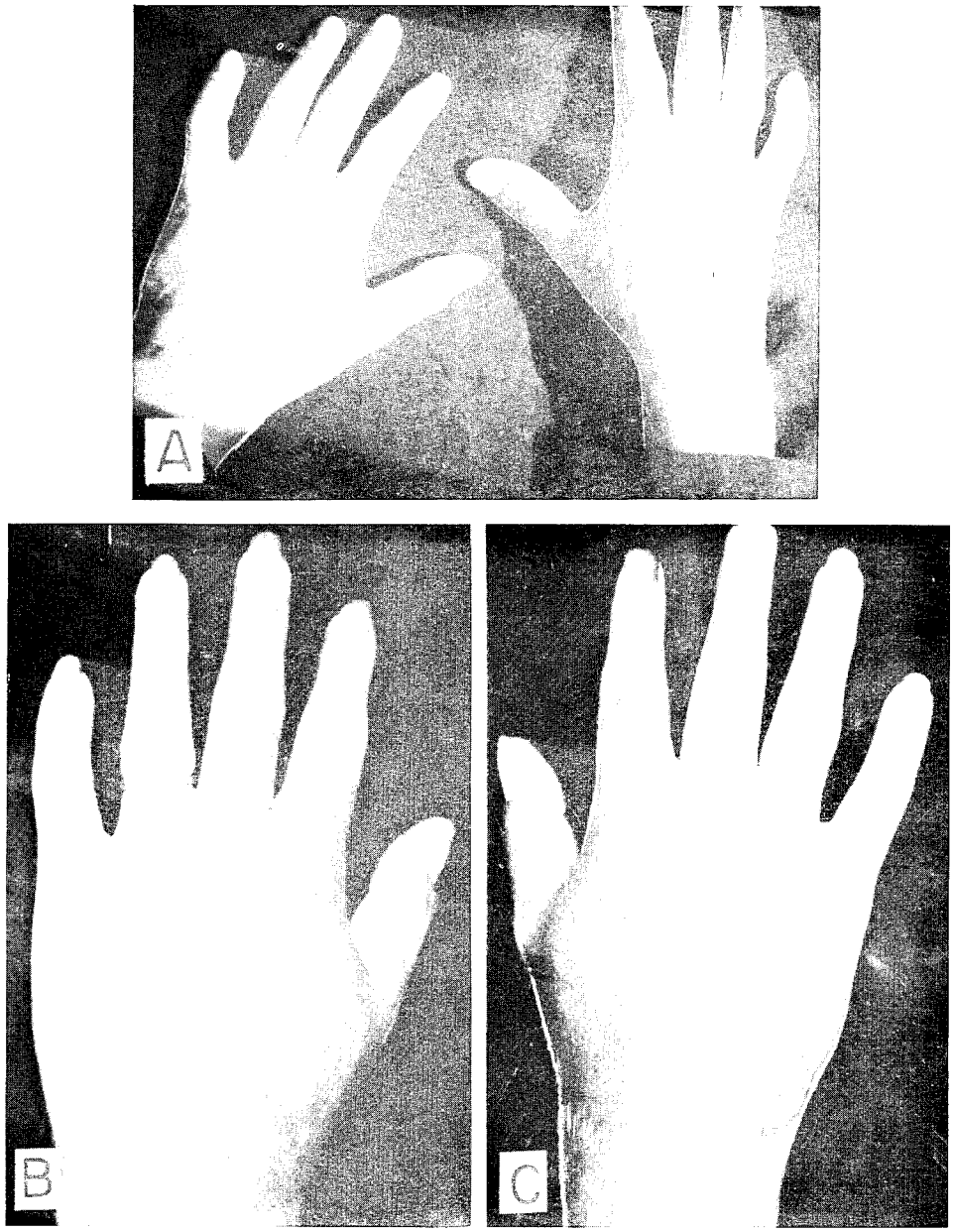



*Figure 162. Fire burns of the hand. A. Scars are thick, heavy, and inelastic; they repeatedly break down. This type of healed burn should be resurfaced. B and C show the result obtained by application of a split graft.*

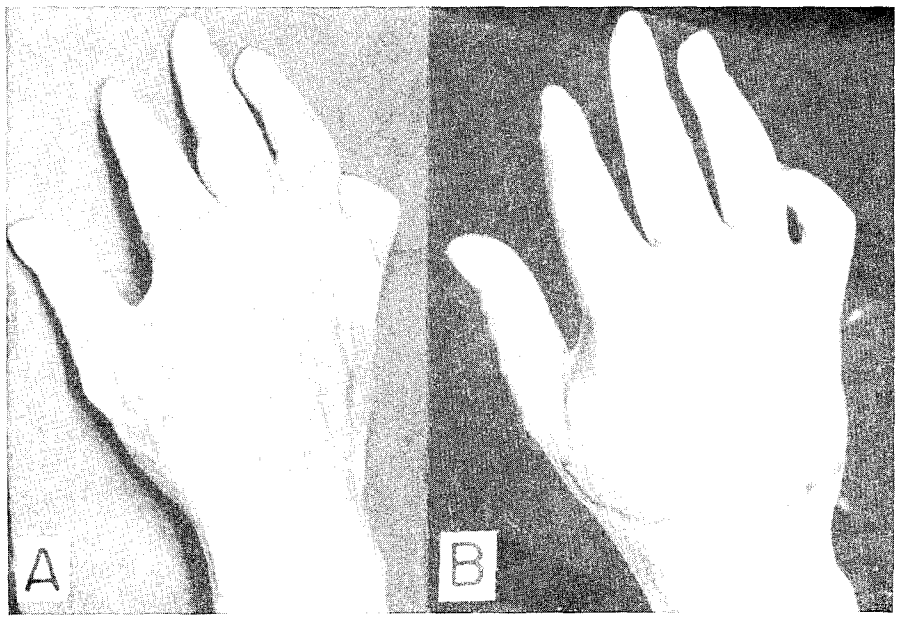



*Figure 163. Burn scars with contracture of the little finger. A. Preoperative condition. Burn scar contractures of the little finger often prove difficult to correct. B. Postoperative result. Resurfacing by split thickness skin graft which encircled the little finger.*

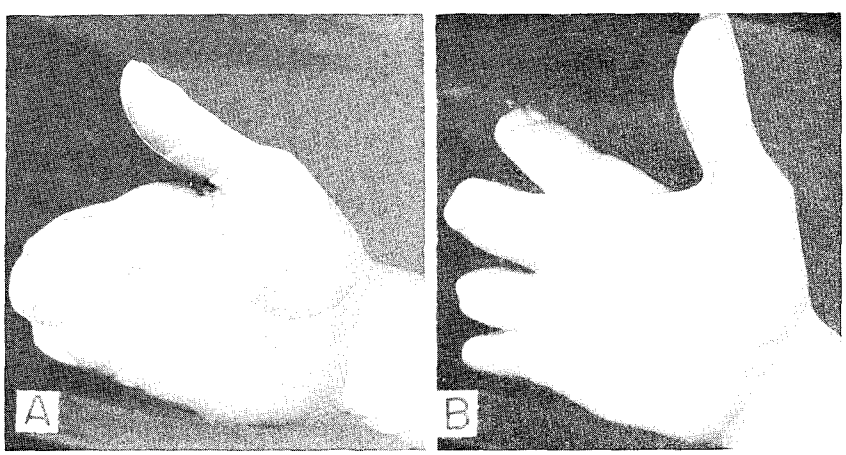



*Figure 164. Burns of the hand with loss of the distal and middle phalanges of the four fingers. A. The proximal phalanges had been permitted to adhere to one another, producing a mitten-like effect. B. Postoperative result obtained by separating the proximal phalanges and applying free skin grafts. A surprisingly useful hand resulted.*

later. Additionally, there might be flexion contracture of the middle finger joints and hyperextension of the distal joints, due to destruction of the central slip of the extensor tendon permitting the lateral slips to become displaced from the dorsum of the finger to the sides. In repairing these, tendon and

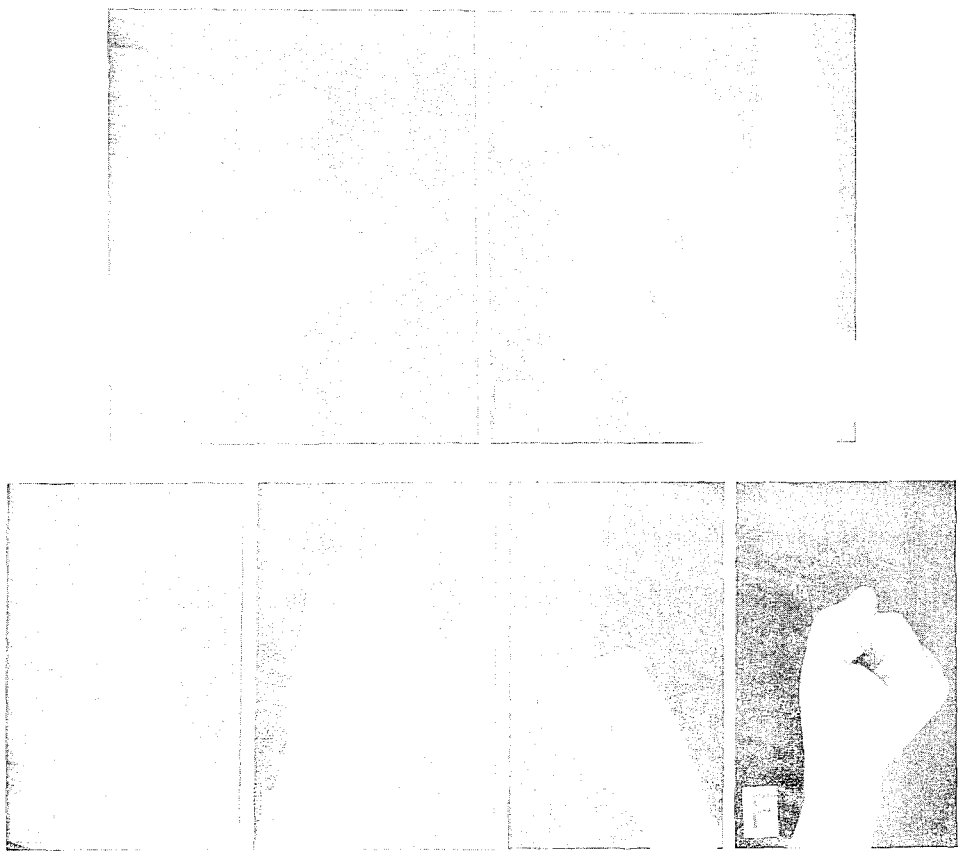


*Figure 165. Severe electrical burns of both hands. The patient had picked up a high-tension wire. A. Left hand. The index finger was completely useless and had to be amputated. The middle and ring fingers had severe flexor contractures. B. Right hand. The index finger is moderately flexed but the middle, ring, and little fingers are severely contracted, with the bones of the distal phalanges of the little and ring fingers exposed, requiring partial amputation. C. Left hand, amount of extension obtained after application of a flap. D. Postoperative result, right hand, showing amount of extension obtained. A flap was applied to the palm and to the palmar surfaces of the middle, ring, and little fingers. The distal joint of the middle finger was arthrodesed and a flexor tendon graft applied to the middle finger. E and F. Amount of flexion obtained in each hand.*

joint surgery was not performed at the time of skin grafting but left for a later stage, after the skin graft had entirely healed. This procedure permitted the surgeon to operate through a healthy covering which would heal readily and obviate failure occasioned by loss of surface tissue.

Surgical treatment of contractures consisted of removing scarred tissue, application of graft, and possible joint and tendon repair.

*Removal of Scar Tissue.* Scarred skin—and fascia if involved—was carefully excised. In carrying out dissection, care was taken not to damage tendons or traumatize them by excessive handling. Vascular arches could be ligated almost with impunity, since they actually form communicating arches, but at least one digital artery has to be preserved on each finger to avoid necrosis.

Injury to neural structures had to be evaded. Deep incisions encircling the base of the thenar eminence extending proximally farther than the midpoint of the thenar crease were avoided, for at this point the deep motor branch of the median nerve, furnishing opponens power to the thumb, enters the thenar prominence. Loss of this nerve would interfere greatly with the useful functioning of the hand. Resuture of the nerve is possible but difficult because of its small size.

At dissection of the scar tissue, bands of contracture could be felt. If these were so located that they could not be excised completely they were incised to permit free, full extension of the hand and fingers. Deep strands of strangling scar tissue which cut off the blood supply distally were carefully removed. Incisions were made long enough to restore the normal commissures of the fingers. After the scar had been excised and the fingers stretched into as full extension as could be obtained, note was made of possible tendon contracture and joint involvement (for the third phase of treatment). These complications were not treated at this time since postoperative stretching and exercise overcame mild tendon contracture to a certain extent. Tendon lengthening and joint operations were delayed until it was determined how much could be accomplished by elastic splinting, physical, and occupational therapy.

*Application of Graft.* Regardless of the type of graft to be applied there were specific conditions to be met if transplantation was to be successful. Sufficient nourishment had to be provided until new blood vessels grew in from the base or bed. Rigid asepsis had to be maintained since even slight infection was sufficient to interfere with a successful take. This was particularly true of full thickness grafts. In general, if asepsis was doubtful it seemed better to delay the operative procedure until it was certain that the infection had been cleared up. Hemostasis of the recipient site was essential. Electro-coagulation was not used to stop bleeding; it leaves small areas of necrotic tissue about each bleeding point, and the necrotic tissue must either by absorbed or slough beneath the graft. The latter is usual, and is likely to produce a number of small areas over which the graft does not take. Actual tissue contact was necessary so that vascular sprouts which would grow up from below would not be

obstructed by the presence of a clot. Avoidance of dead spaces was therefore important, and postoperative immobilization not only desirable but indispensable in free grafting, in order to ensure a firm tissue contact between the transplant and the recipient area and to avoid the possibility of even the slightest bleeding. Successful repair required a complete, 100 percent take of the graft. A partial, haphazard take resulted only in scar formation and subsequent contracture. Precise attention had to be paid to every step of the operation and the dressings and no detail was too small to be overlooked.

In grafting the palmar surface, *if the burn was no deeper than the skin*, preference was given a free full thickness skin graft. It was simpler than a flap, and experience had proved it to be most satisfactory; it was quicker, since it was a one-stage procedure; postoperative dressings were reduced to a minimum, and prolonged immobilization avoided. All operative wounds on the hand were closed immediately, avoiding the danger of low-grade infection.

The scar tissue on the dorsum often could be stripped away almost as one skins a rabbit. If the skin alone was involved, it was repaired very successfully with a thick split or intermediate thickness graft. The graft might be taken from any nonhairy area where the skin is of normal thickness, such as the thigh, abdomen, or arm. If it was necessary to use hair-bearing skin, it had to be remembered that it might later grow hair.

Where a split graft was used, better scars resulted if the graft was fitted in and sutured edge to edge, although this procedure required more time than a graft sutured so that it overlapped the skin margins.

With fingers in full extension, a pattern of the exact defect was made. This could be traced on oiled silk film celluloid or rubber tissue, or a piece of dry, flat gauze might be firmly pressed down upon the raw surface to obtain a clear blood-stained imprint of the area to be grafted.

The graft was cut exactly to pattern, neither larger nor smaller, and sutured into its new site under normal skin tension. (This is particularly important with the full thickness graft.) Using a graft larger than the recipient area might result in wrinkling and subsequent interference with the take. If the skin graft is too small and is stretched to fit the defect, even though it might take, the resultant tension causes elastic fibers in the skin to become fibrotic and long afterward to contract. Subsequent pigmentation was of no particular significance; it was permanent and there was no way of preventing nor curing it.

If a dermatome was used to cut the graft, it was set at approximately .022 to .025 inch. If a full thickness graft was to be placed, all fat was trimmed away from its undersurface after the graft had been detached from its base. The graft was carefully and accurately sutured into place. At no time was it allowed to dry out.

If a full thickness graft had been used, the donor area was closed by the assisting surgeon while the graft was being applied. The skin edges were

undermined and the wound closed by sliding the edges together and using deep reinforcing sutures or a relaxation incision if necessary, to take the tension off the wound edges. The skin edges were well approximated to facilitate prompt healing. Closure of the donor area was done with care, for even though the graft on the hand might take, an open, slow-healing wound might result at the site from which the graft was taken. Donor areas for split grafts were dressed in the usual manner, i. e., greasy fine-mesh gauze in contact with the raw surface, then an even firm bandage.

In interdigital clefts or webs, the patient subsequently might develop minor secondary contractures necessitating small additional grafts later. If there was normal skin in the webs, this contingency could be avoided (Fig. 166).

Application of the dressing and immobilization of the hand were important. The fingers were well extended and spread apart. The graft was covered with a smooth layer of sterile fine-mesh 5 percent xeroform (bismuth tribromphenate $(C_6H_2Br_3O)_2BiOH+Bi_2O_3$) gauze, followed by a layer of

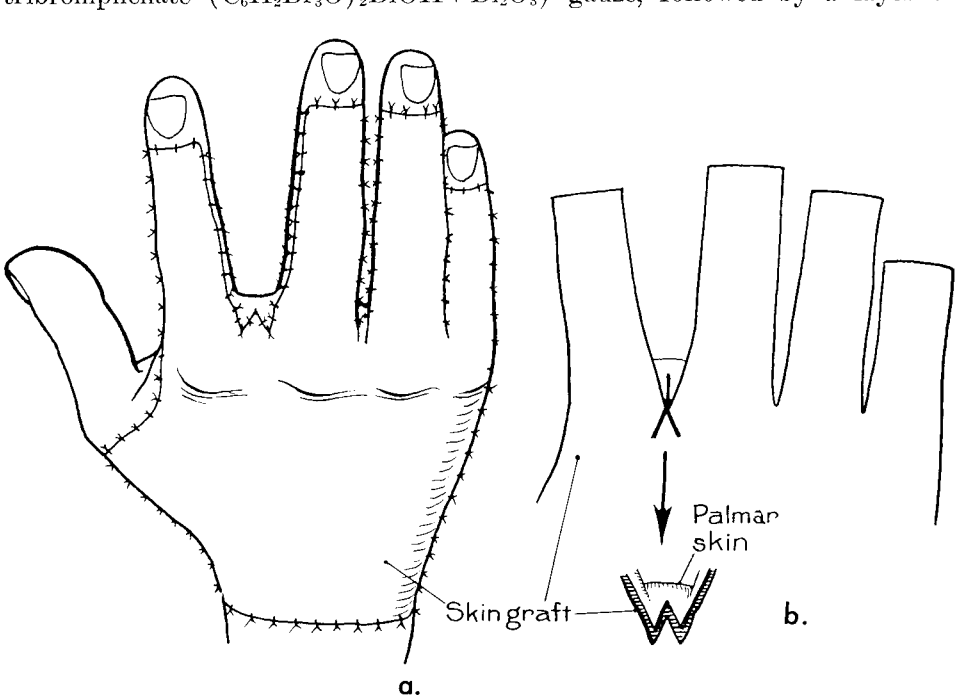



*Figure 166. Small secondary contractures in the webs sometimes necessitate the additional application of grafts at a secondary operation which may be avoided by carrying out the maneuver termed "gusseting." a. A split or intermediate thickness skin graft applied to the dorsum of the hand with gussets in the web. b. Detail of the gusset. An inverted V-shaped incision is made at the beginning of the digitation of the graft. This will provide a small V-shaped flap which will fit between two small flaps on the palmar skin.*

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plain gauze, then by fluffed gauze or cotton waste. A molded, padded plaster of paris splint was applied and when it had hardened the hand was bandaged to the splint with moderately firm pressure to prevent accumulation of blood or serum beneath the graft. A constricting bandage was avoided. If possible, fingertips were left exposed so that they might be watched for signs of circulatory deficiency, evidenced by color, temperature, and sensory changes. Occassionally one or more of the fingertips might appear slightly cyanotic before the dressing was applied. When collateral circulation had become well established, normal color usually returned within 24 hours.

After the patient was returned to bed, if a free graft had been used, the entire forearm was elevated to aid venous return, and the part kept at complete rest.

If there was no indication of infection or failure of take (as indicated by a rise in temperature, characteristic odor, or drainage from the hand), the usual routine postoperative treatment was carried out. The dressing was removed about the seventh day, although it might be reinforced prior to that time if required to maintain the proper pressure and immobilization. Upon evidence of infection, it was removed immediately and a dressing saturated with a solution of 250 units per cubic centimeter of penicillin (if the causative organism was susceptible), or one of the chlorinated antiseptics applied. Fortunately, infection was very rare. Wet dressings did not damage the viable portion of the graft, and they speedily cleared up the infection.

Sutures were removed about the 8th to 10th day. Immobilization was maintained 2 to 3 weeks. Removal of the first dressings might be so painful as to indicate doing them under thiopental sodium and oxygen anesthesia.

After the graft had taken completely and there was no danger of its separating from its base (usually about 3 to 4 weeks after the operation), gentle massage and motion were undertaken. If complete extension had not been accomplished, physical therapy was started (massage and stretching under warm water). Elastic splinting often mobilized stiffened joints. If, after a thorough course of treatment including occupational therapy, these measures failed to accomplish the desired result, tendon lengthening and operation upon the joints might be necessary.

## Nerve Suture

Intact innervation is essential not only from the motor, but also from the sensory point of view, since without sensation the finger becomes atrophic and may ulcerate.

If the nerves in the finger had been completely destroyed over a long distance, there was no hope for useful reconstruction of the finger. If, however, the nerves were present in the finger but divided, every effort was made to suture them as early as possible. Results of digital nerve suture were so

rewarding (successful in 75 to 80 percent) that every reconstructive effort was justified, even in the most difficult cases. If both nerves and tendon had been damaged, the nerves could be sutured at the time the tendon was repaired. The bloodless-field principle held for both types of repair in the fingers. In suturing the nerve, both ends were identified. In longstanding cases where there was a neuroma on the proximal end, it was carefully trimmed away, and the most accurate coaptation of the freshened nerve ends carried out, using the finest silk (No. 6–0) on atraumatic needles. Metal sutures such as tantalum were not used. The blood vessel running along the nerve sheath served as a guide for apposition. In order to obtain slack, it was necessary to dissect the nerve proximally and to flex the finger joints and wrist, since flexion shortened the course of the nerve.

Immobilization by splinting, similar to that used in flexor-tendon repair, was applied and maintained for about 4 weeks. The joints could then be gradually extended. In general, the amount of regeneration was estimated as approximately one finger segment per month. The growth of new axones was progressive; the extent of the regeneration could be ascertained by Tinel's sign.

No nerve grafting was done by the hand section at this hospital.

## Bone Grafting

One injury often seen involved the bones of the metacarpals with destruction of the surface covering. In practically all of these it was necessary to cover the denuded area with a flap prior to realining or grafting the bone of the ununited metacarpal fracture. This practice conformed to the fundamental principle not to attempt repair of the deeper structures unless the surface tissue was stable. Sources of bone grafts were three: The upper posterior portion of the ulna of the same arm for a key or peg, if a small graft was required; the tibia for a long graft, and the crest of the ilium for a massive graft, or for a defect requiring bone-forming potentialities.

Grafts were placed and fastened in a variety of ways. If the break was accompanied by slight loss of bone, the small key graft from the ulna was used, primarily to hasten healing. It was also used as an intramedullary peg. This method requires no fixation. When there was not enough soft tissue relaxation to permit both ends of the bone to be slipped over the peg it was necessary to cut a dovetail or slot in the proximal fragment. Thus the graft was used as an intramedullary peg in the head, and as a mortise joint in the shaft. At the latter site, small stainless steel wire usually held the graft in place. Another method of fastening and immobilizing the graft was by the use of Kirschner wire—particularly helpful when iliac bone was used. A simple procedure for placing the wires was devised. The conventional type of eggbeater hand drill was not satisfactory because of its length and general clumsiness, and with this type of instrument it was impossible to place

the wires quickly and accurately. A small pin vise was altered so that it could be used as a drill chuck and was held in a power-driven saw. This simple device proved extremely efficient and timesaving (Fig. 148 d). Several other small instruments, such as small circular saws for trimming the metacarpals, cutting slots, and drilling holes were also utilized (Fig. 148). These cutters were held in a simple arbor that avoided the use of a bulky, cumbersome chuck.

Simple, metal racks which could readily be sterilized were designed to prevent damage to the cutting edges of sharp instruments (Fig. 149). These racks were used for chisels and tendon strippers.

## Repair of Joints

Restoration of joint motion was always carried out before tendon repairs were undertaken. Finger joints were particularly prone to stiffen, especially in the presence of an open wound. One of the most troublesome problems encountered in hand surgery in war casualties was mobilization of finger joints stiffened by faulty or prolonged splinting at the time of injury. Patients often had splints applied to the forearm, hand, and fingers, in a single flat, rigid splint. This is one of the surest ways of producing rigidity of all finger joints when the digits are in the straight position and the collateral ligaments of the metacarpophalangeal joints at their shortest dimension, and therefore lax. When the joints are flexed, the collateral ligaments are on the stretch. Thus, during splinting, if the finger is in the straight position there is a tendency for the relaxed collateral ligaments to contract, producing rigidity. This is particularly true if the hand has been injured, with edema and inflammation products present. The principles of splinting described by Koch and Mason were followed with good results, and in the future the universal Mason-Allen splint should be standard equipment for all hand work. It protects the normal position of function of the fingers as well as the metacarpal arch.

Elastic splinting for the mobilization of joints accomplished a great deal except in those instances of completely frozen joints. Roentgenographic examination of all stiffened joints was routine before any treatment whatsoever was undertaken. Obviously, in cases where there was actual damage to the joint surfaces, or ankylosis, elastic splinting would be useless. Where there was no demonstrable roentgenographic change, elastic splinting accomplished a great deal. The type of flexion splint used was the Bunnell knuckle bender, later modified to produce flexion of the middle phalanx by adding another piece to the splint.

Capsulotomy of the collateral ligaments of the metacarpophalangeal joints was resorted to in cases where it was not possible to mobilize the proximal finger joints. More properly, this should be referred to as capsulec-

tomy, since incision of the collateral ligaments was never sufficient but excision of both collateral ligaments was necessary.

To approach the collateral ligament, a dorsolateral incision on each side of the proximal finger joint was used. The tendon of the interossei was retracted and the joint capsule exposed. The collateral ligament was excised as extensively as possible. When the ligaments on both sides of the joint had been ablated, the surgeon was able to move the finger through a fairly good arc. If this could not be done, either the operation had not been performed properly, or there was some other condition interfering with movement. Following operation, the joint was splinted in flexion and so maintained for about 2 weeks, or possibly a few days less if the skin incisions had healed well. Exercise and elastic traction with the knuckle bender were conscientiously carried out.

A very simple elastic flexion device was effectively used postoperatively (Fig. 167).

As a rule operations on capsules of the middle and distal finger joints produced results that left much to be desired. Arthroplasty in this location was

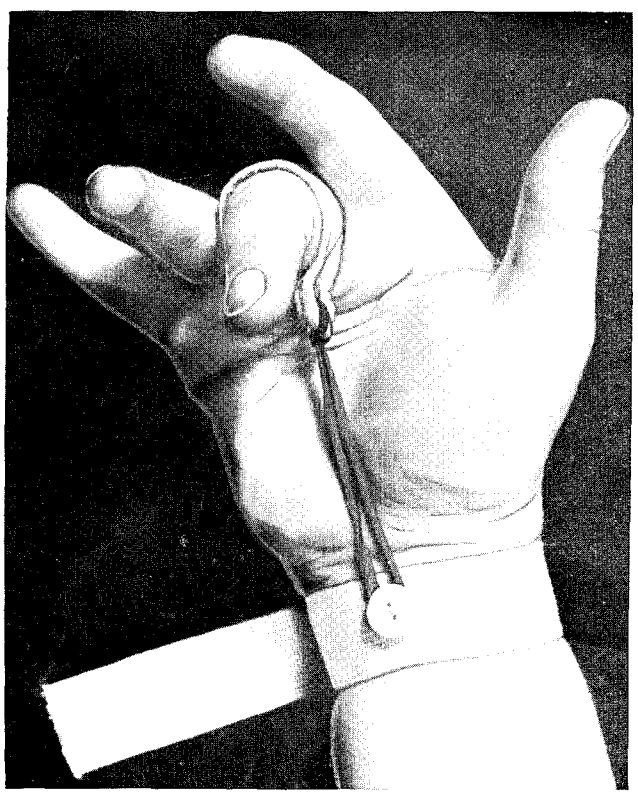


*Figure 167. Simple device used to exert flexion on proximal joint of finger, particularly after capsulotomy or arthroplasty.*

disappointing; instead these joints were generally arthrodesed in slight flexion; the midlateral incision was used, the joint surfaces freshened, trimmed to the proper angle, and bony approximation secured with Kirschner wire followed by immobilization in plaster.

Arthroplasty of the proximal finger joints was resorted to when true ankylosis existed, or the joint surfaces damaged. Satisfactory results were obtained. The same type of incision was used as that for capsulectomy of the collateral ligaments. When the joint was exposed, the capsular ligament, or whatever remained of it, was ablated after retracting the aponeurotic sleeve and the interosseus tendon. If necessary, the proximal end of the phalanx could be smoothed. The head of the metacarpal or its remnant was trimmed down to leave a space of about half an inch. The remainder of the distal end of the metacarpal was then trimmed either with a bone rasp or a sharp chisel to form a sort of rocker. A piece of fascia lata was wrapped around the distal end of the metacarpal and a fascial prolongation extended proximally beneath the extensor tendon to prevent it from adhering to the bone. After closure, the hand was immobilized with the proximal joint flexed at about 90 degrees and the wrist in dorsiflexion. Early motion was always instituted.

## Tendons

Tendon repairs such as suture, tendolysis, and tendon grafts were done in considerable numbers. The technique of Bunnell was closely followed (Chapter II). In general, results were in line with those obtained elsewhere. Most successful were operations on the dorsum of the hand or forearm and least successful, those on the flexor tendons.

## Amputations

Amputation of digits was resorted to only when no improvement in function could be obtained, for a functionless finger often interferes mechanically with other digits. Unless the patient could be convinced that he would be better off without it the finger was not amputated. If any other digits on the same hand were missing, painstakingly strenuous efforts were made to avoid amputation of any finger. The guiding criteria were: The presence or absence of stable and adequate surface covering; sensation, and the possibility of restoring sensation; joint motion; and normal tendon and muscle function. There were but two cases in the whole hospital experience in which amputation of the entire hand was recommended. Only if the hand was completely useless was amputation advised.

Partial amputations of the finger were resorted to when the distal end was covered with poor, insensitive skin, or the finger was likely to get in the patient's way. It was considered better to have a slightly shorter finger stump

covered by normal skin than a longer stump covered by a less perceptive sensory tip made up of a skin graft. In certain cases, the skin of an amputated finger with the bone removed was used as a tube pedicle to repair the stump of another finger (Fig. 168).

Quite frequently a painful unstable stump was encountered after traumatic amputation. At operation one usually found sharp, bony spurs covered only by scar and without adequate subcutaneous tissue, projecting from the distal end of the finger. These were best treated by smoothing off the sharp spurs and, if necessary, trimming the bone sufficiently so that the tip might be covered with a flap of healthy skin (preferably palmar) with adequate subcutaneous tissue. Care had to be taken not to have too flabby a covering. The final scar was at the tip toward the dorsal rather than the palmar surface of the finger. If the finger itself was useless and there was either a palmar or a dorsal scar on the hand, the finger might be filleted and the skin covering reflected to replace the scar of the hand.

## Reconstruction of Digits

The thumb is the hand's most important digit and its loss results in serious interference with function. Surgical restoration was carried out in some patients and produced satisfactory results (Fig. 169).

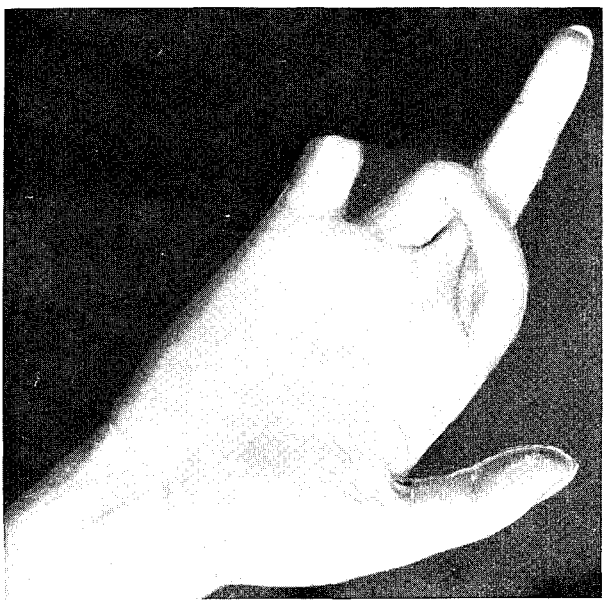


*Figure 168. Utilization of skin of useless finger to repair stump of another finger. In these operations the useless portion of the finger was filleted, tubed, and migrated in a single stage.*

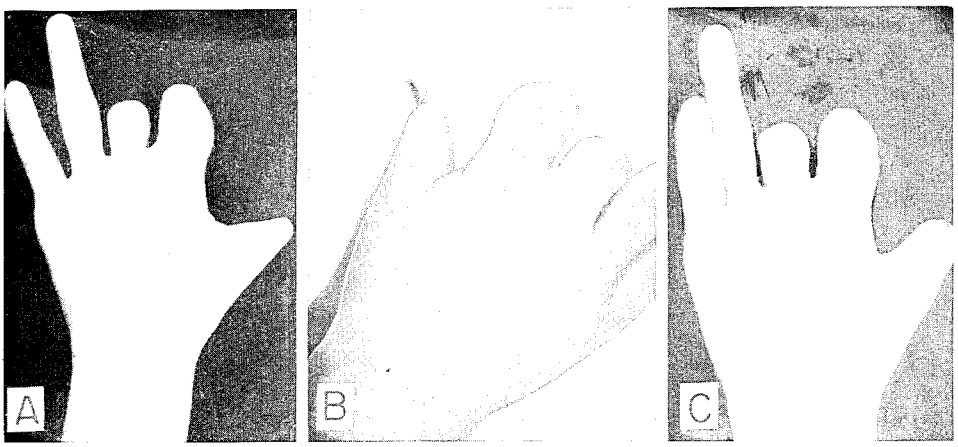



*Figure 169. Partial restoration of thumb. A. Palmar view. B. Immediate migration of one end of tube pedicle to restore the thumb. C. Final stage.*

*Partial Loss of Thumb.* Occasionally the amount of thumb loss was so slight that operative restoration was not practicable. More frequent were those cases in which there had been a loss of the distal phalanx which had healed with the formation of an adherent scar over the stump. In repairing these, the surgeon was usually forced to choose between length of finger and preservation of highly specialized sensation. It was possible to lengthen the finger by utilizing a flap of skin, but if this flap were taken from a distant region (that is, not the skin of finger or palm), it would never develop stereognosis, although in time it would develop primary sensation.

Partial loss of the thumb which had healed with scarring on the distal and palmar aspects of the amputation stump constituted a troublesome problem. It seemed ill-advised to attempt to replace the tip with a free graft or distant flap. Occasionally, flaps from the palm of the hand itself were used successfully to replace a missing fingertip, but when the thumb was involved it was difficult to obtain a flap from the hypothenar eminence or base of the palm. With rare exceptions, it was advisable in such a case to shorten the thumb and use the normal palmar skin to replace the scar and cover the distal end of the thumb stump. (This may necessitate shortening the thumbnail.)

Occasionally a patient was seen who had sustained a partial or subtotal loss of the thumb and whose index finger, although possessing normal sensation, was functionless because of bone, joint, and tendon damage. In this type of injury the end of the index finger can be transplanted to repair the thumb (Fig. 170). Such a transplantation was performed on a young officer who had sustained a gunshot wound of the hand. The projectile shattered the distal portion of the thumb and then passed through the proximal joint of the index finger, destroying the joint, the flexor and extensor tendons, and the

skin covering. The circulation of the index finger was not affected and the digital nerves were also intact.

Since this index finger was practically useless, a decision was made to transplant a portion of it to the thumb to increase its usefulness. At first operation a mid-dorsal incision was made on the index finger from the proximal to the distal finger joints; the extensor tendor was reflected to one side, and the digital nerves and vessels preserved. The bones of the proximal two phalanges were filleted, leaving a tube of skin, its distal end consisting of the index fingertip with its phalangeal bone, digital vessels, and nerve. At this operation the distal end of the thumb stump was freshened by doing a guillotine amputation through the distal joint. The distal end of the bone of the proximal phalanx itself was not disturbed. The long extensor tendon of the thumb was identified. The index fingertip was then migrated to the thumb stump, and after uniting the extensor tendon of the index finger with that of the thumb, the remainder of the suturing was carried out. Tendon suture was not performed with the idea of restoring motion to this transplanted fingertip, but for the purpose of stabilizing the joint.

The migrated fingertip healed in place uneventfully, and approximately 6 weeks after the first operation, nerve suture was performed. Midlateral incisions were made on the pedicle of the index finger and the digital nerves exposed well proximal to the distal joint. In similar manner, through midlateral incisions on the proximal phalanx of the thumb, the digital nerves of the thumb were exposed and dissected out distally to their ends. Using No. 6–0 black silk on atraumatic needles, the nerves were sutured, uniting the proximal end of the nerve of the thumb to the distal end of the nerve of the transplanted index finger. The same procedure was performed on both pairs of digital nerves. The nerve suture was located distally so that the new growth of axons would be as short as possible. At this same operation, the digital arteries in the pedicle of the index finger were tied off, to compel the fingertip to derive its entire circulation from the vessels of the thumb. It would have been possible to sever the pedicle at this stage, but it was preferable not to do so in this instance. In approximately 5 weeks, the patient developed a good return of sensation in the migrated tip; this sensation was associated with the thumbtip.

A third operation was performed about 6 weeks after the second. At this stage the pedicle of the index finger was severed, and the flexor profundus tendon of the index finger sutured to the long flexor tendon of the thumb. Here again, it is emphasized that this was done for the purpose of stabilizing the joint, and not with the idea of giving motion to the fingertip. The second metacarpal bone was trimmed down later and the patient gained a stable, useful thumb, with good sensation.

*Subtotal Loss of Thumb.* In subtotal losses of the thumb, where a mobile metacarpal covered with a good scar remains and the patient is able to grasp,

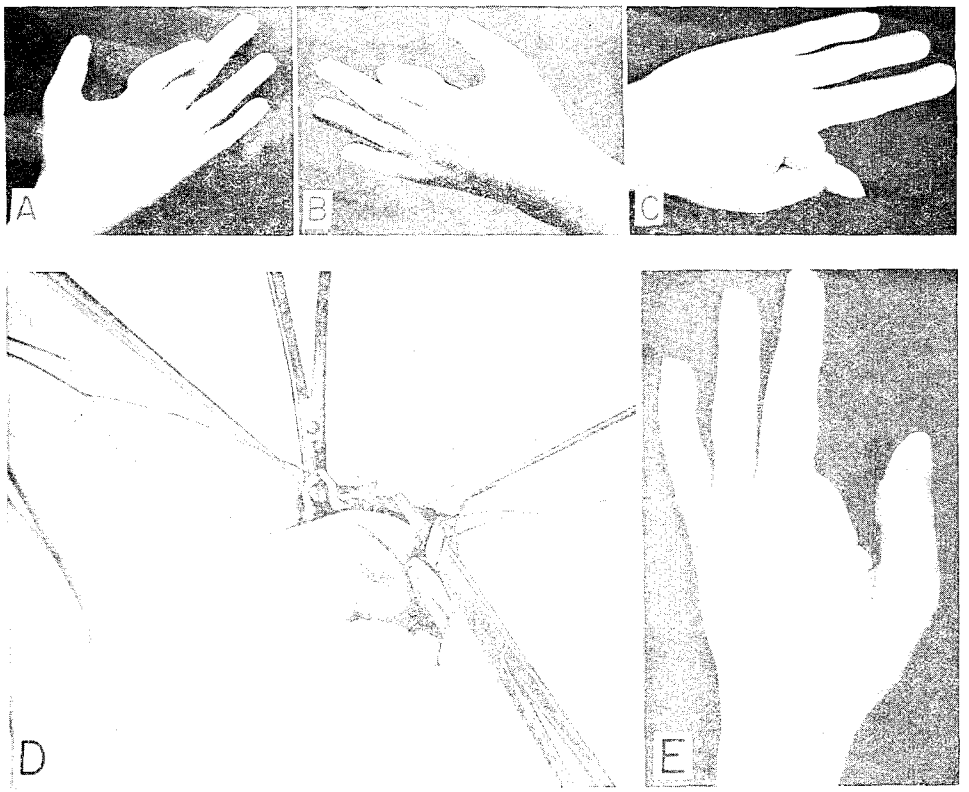



*Figure 170. Transplantation of distal end of useless index finger to restore partially amputated thumb. A. Palmar view of useless index finger. B. Dorsal view. C. Hand after first stage of transplantation. D. Suture of digital nerve of thumb to digital nerve of transplanted index fingertips. E. Postoperative result. Entirely normal sensation developed in the transplanted fingertip. F. Preoperative roentgenogram. G. Postoperative roentgenogram showing distal phalanx of reconstructed thumb. The second metacarpal was subsequently shortened.*

surgery may not be necessary. As a general rule, however, the prehensile function of the hand is much improved if the web is deepened by Z-plastic operation, with transposition of flaps.

If conditions permitted, subtotal losses of the thumb could be repaired by migration of another finger, as described previously. A restoration of this type should always include nerve transplantation and suture.

Phalangization of the thumb metacarpal was often very helpful in aiding the prehensile function of the thumb. This could be brought about by using either a flap or a free graft. While it was desirable to obtain as deep a web as possible, muscular attachments were not sacrificed. If they had already been

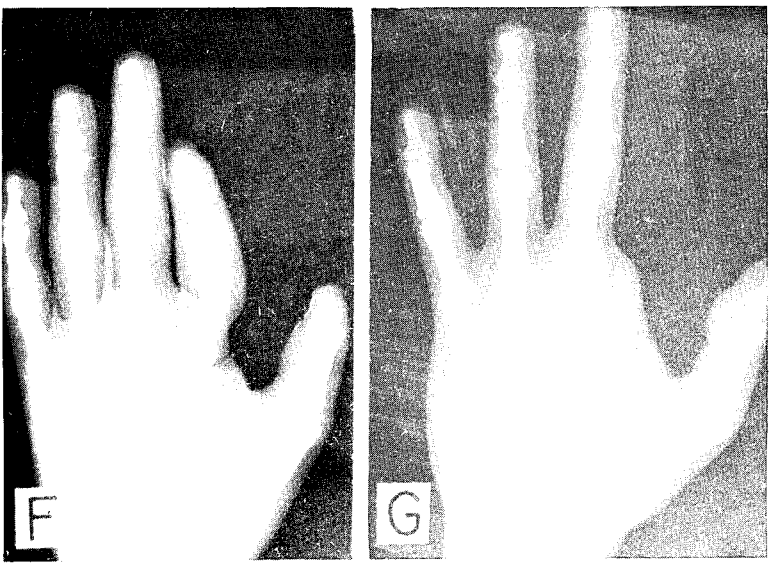



*Figure 170*—Continued.

damaged, a tendon transplant to bring about opposition, as described by Bunnell, was used.

*Total Loss of Thumb.* Total loss of the thumb, including loss of the metacarpal, reduced the efficiency of the hand by approximately 40 percent. Such a hand lacks opposition and cannot perform those functions which require prehensile movements. Some patients who had lost the entire thumb developed astonishing dexterity and did not wish to have any surgery done, nor did they desire a prosthesis.

Surgical restoration for total loss of thumb could be accomplished in a number of ways. The presence of even a small proximal portion of the metacarpal which had mobility, greatly increased the usefulness of the surgical restoration.

If the index finger was present and if it was advisable to use this finger to replace a lost thumb, first the metacarpal was phalangized, then it was separated from the third metacarpal, with the flexor and extensor tendons, the vessels, and the nerves, kept intact. The digital nerve of the index finger was split from the common digital nerve which supplies the ulnar side of the index finger and the radial side of the middle finger. The raw area between the second and third metacarpals was covered with a flap of skin of generous size to permit the migration of the metacarpal of the index finger to the position of the thumb. At a subsequent operation, the index metacarpal was migrated to the position of the thumb and rotated so that the index finger was placed in the position of opposition. At the same time the metacarpal was shortened.

In those cases where it was desirable to provide an immovable post in the position of opposition, an abdominal tube pedicle was prepared at the first operation. Next, one end of the tube was migrated to the thenar eminence. The scar was located in a neutral position away from areas of friction and use. At a third stage, the abdominal end of the pedicle was divided. Since the distal end of the tube is a terminal structure, it is a good idea to clamp off the pedicle prior to severing it. A rubber-covered clamp was applied distal to the site at which the pedicle was to be divided. At the first trial, the clamp was applied only for a few minutes. If the portion of the pedicle attached to the hand did not become cyanotic, the pedicle could be clamped on succeeding days for longer periods of time. If there remained any doubt about the vigor of the circulation, it was best to sever the pedicle partially and to wait about one week before detaching it completely.

A bone graft could be inserted in the pedicle at the third-stage operation, but it was more desirable to implant the bone at a later stage for the reason that the distal end of the tube might heal slowly; if a bone graft had been inserted there was a possibility that the skin would break down and endanger the result. Various sources were tried for bone grafts: Tibial bone, both straight and angulated; the curved portion of the ilium; and finally, a rib graft. The angulated or curved graft was most desirable, and the iliac graft preferable to the tibial, since the former healed more readily. The rib graft has no particular advantage. The angulation or curve of the graft was designed prior to the operation.

Straight grafts from the tibia were cut with the twin-bladed rotary saw from the upper part of the anteromedial surface; anatomic margins were avoided. A rotary burr was used to cut the ends of the graft. When an angulated graft was taken from the tibia, the reciprocating saw was used. A curved graft taken from the crest of the ilium was removed with a wide, sharp chisel. When rib was used (preferably the 11th or 12th), it was removed in the usual manner, using Doyen rib elevators and rib shears.

Placement of the bone graft required great care for unless the thumb post is in the proper position its efficiency is markedly decreased. The post should not be too long; this would tend to interfere with the closing of the fingers. When the post was of the proper length, the patient could pinch against it with the index and middle fingers by *fixing* the two distal joints of each finger and moving the metacarpophalangeal joints. When the post was to be cleared by the fingers, the two distal joints were flexed first, following which the metacarpophalangeal joints were flexed.

Shaping the bone graft was expedited by the use of a simple bone vise (Fig. 150) and power-driven instruments (Fig. 148). The general shaping of the bone graft was done with a rotary file. All sharp edges were smoothed and the distal end carefully rounded. The graft was then placed in the bone

vise, proximal end up, and the peg-former (Fig. 151 a) in the rotary saw handle driven down on the graft to form a peg of the same diameter and length as the drill hole. The graft was then placed in the hole which had been prepared for it, and if it fitted satisfactorily, fastened in situ. All grafts were fastened with stainless steel Kirschner wire driving the wire in under power with the simple, efficient device previously described (Fig. 148 d). With this power-driven device, the placement of the wires was accomplished with ease and precision. Two wires were usually sufficient to hold the graft securely. They were left in indefinitely unless they became loose, or, if roentgenographic examination disclosed absorption around them, they could be removed.

Skin covering was carefully sutured over the bone graft and a simple plaster splint applied to immobilize the thumb and wrist. The cast was removed after about 3 weeks and replaced by a protector, as illustrated in Figure 171. This protector served to immobilize the graft and to prevent injury to the skin. It must be stressed that the development of sensation in the restored skin may take a year. During this time the restoration may be damaged. Protection over the interval while sensation is developing is therefore important, and the patient should be cautioned in the care of the restored thumb (Fig. 172).

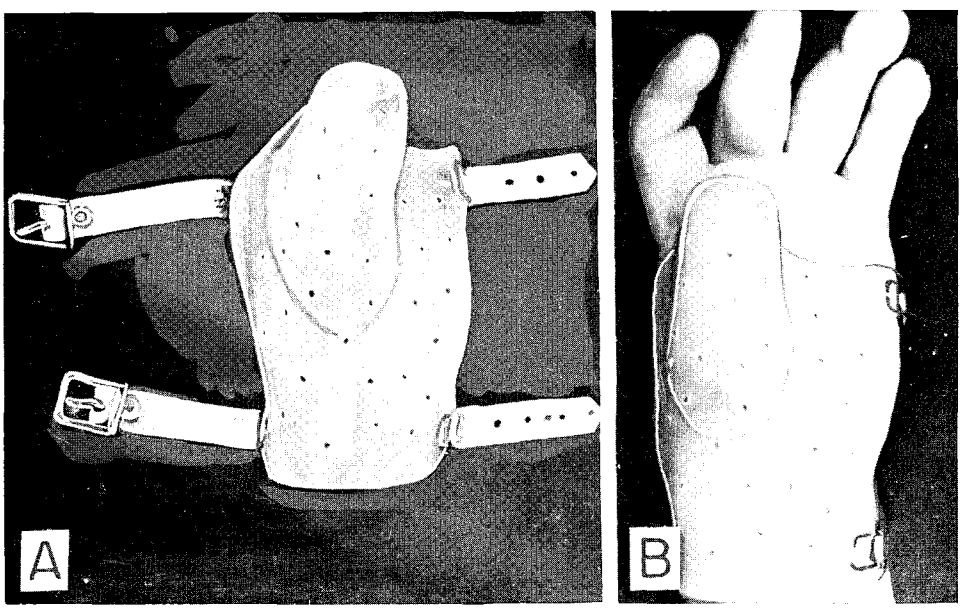



*Figure 171. Thumb protector (designed by Lt. Col. Arthur J. Barsky and constructed by the Dental Department, Northington General Hospital). A. Combined splint and thumb protector of transparent plastic, used to protect restored thumb from damage until skin sensation had developed. B. Thumb protector in use.*

Figures 173, 174, and 175 show a number of thumb restorations, using different types of bone grafts.

The only complication in this type of restoration was ulceration of the distal end of the thumb-tube before the implantation of the bone graft, which could be attributed to early severance of the tube without progressive clamping off of the circulation.

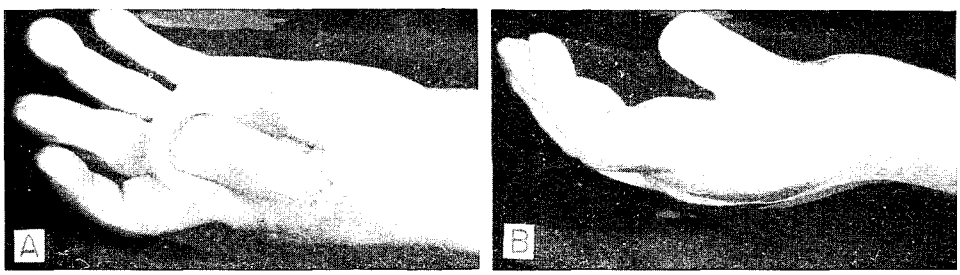



*Figure 172. Reconstructed thumb. A. Volar view. B. Profile view.*

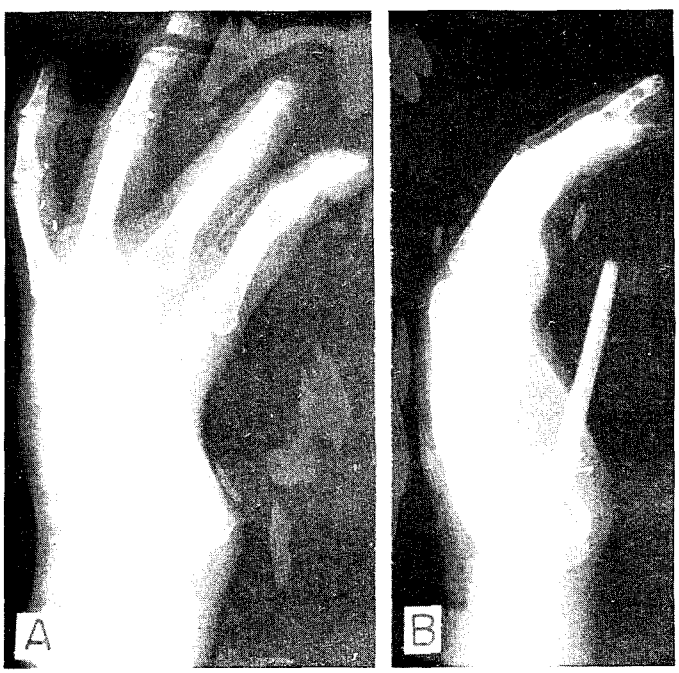



*Figure 173. Restoration of thumb by straight tibial graft. A. Roentgenogram, before restoration. B. After restoration. The proximal end of the graft was shaped into a peg by means of a bone vise (see Fig. 150) and the drill hole prepared by a special end-cutting drill (see Fig. 151). The graft is immobilized by Kirschner wires.*

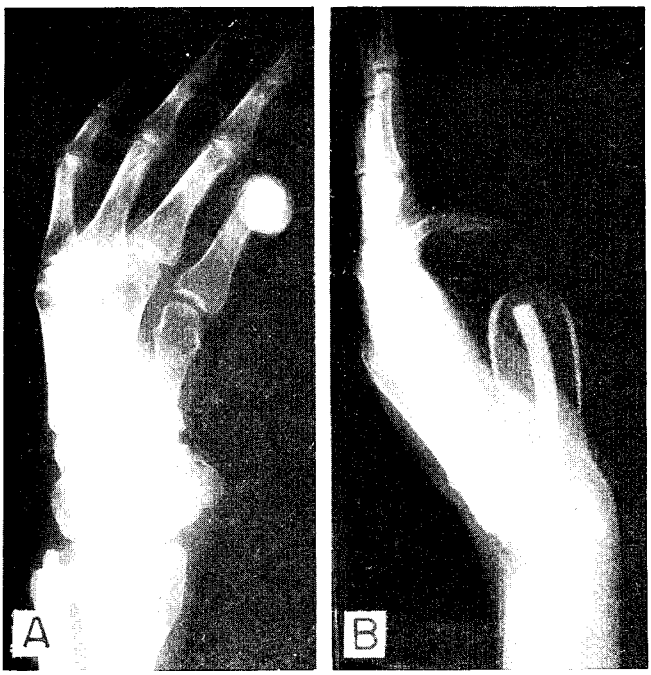



*Figure 174. Restoration of thumb by angulated tibial graft. A. Roentgenogram before restoration. B. After restoration.*

Patients whose four fingers as well as the thumb were lost, with a resultant mitten type of hand, could be benefited by phalangization of the thumb metacarpal (Fig. 176).

### Prosthetic Appliances

The simplest form of prosthesis was similar to the "sailor's palm." Although the sailor's palm was not designed for prehensile movements, if the palmar portion were elongated the fingers could flex upon the post for grasping. The prosthesis consisted of a restoration made of acrylic resin, with its distal end slightly roughened to prevent slipping, made with a sort of bracelet arrangement to attach it to the hand. This thumb prosthesis is shown in Figure 177. It is, of course, a work not a "dress" prosthesis. Those patients who had the desire and the persistence to learn to use a prosthesis found it very helpful.

## REHABILITATION

Physical and occupational therapy were important adjuncts to hand reconstruction. Physical therapy hastened softening and limbering up of the tissues, though occupational therapy, on which great stress was placed, was more important in strengthening the restored hand. Each officer in the hand section had

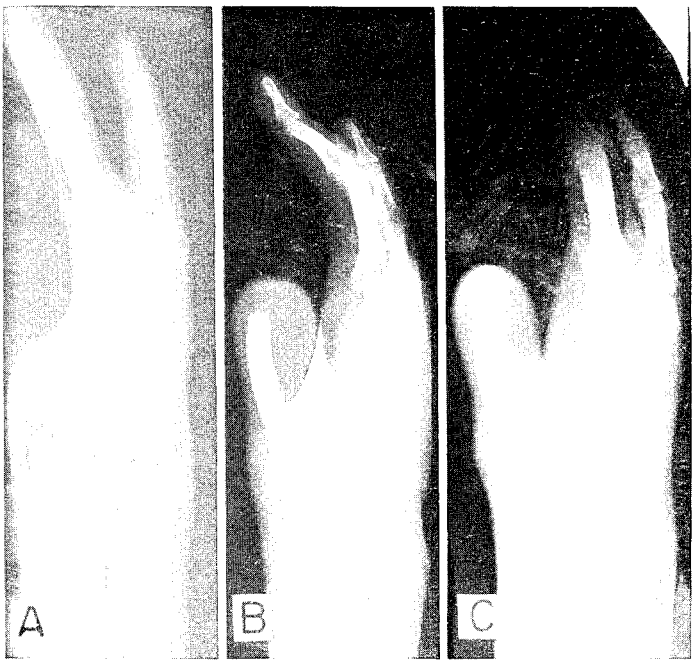



*Figure 175. Restoration of thumb by curved iliac graft. A. Roentgenogram before restoration. B and C. After restoration.*

a numbered list of occupational therapy procedures calculated to produce the results desired in a particular condition. These were transmitted to the occupational therapy department merely by number. In the main, this list was composed of procedures recommended by Bunnell (Chapter II).

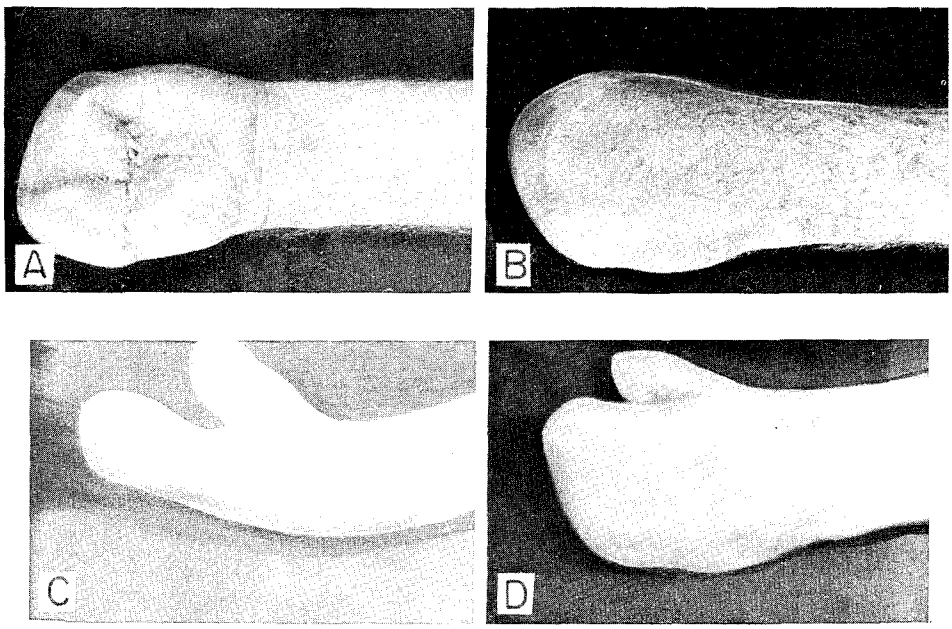



*Figure 176. Repair of mitten hand by phalangization of thumb metacarpal. A. Palmar view with thumb and all four fingers amputated. B. Dorsal view showing flap, placed on hand overseas. C. Profile view after phalangization of first metacarpal. D. Dorsal view. The rudimentary thumb achieved by this operation is of great usefulness to a disabled patient.*

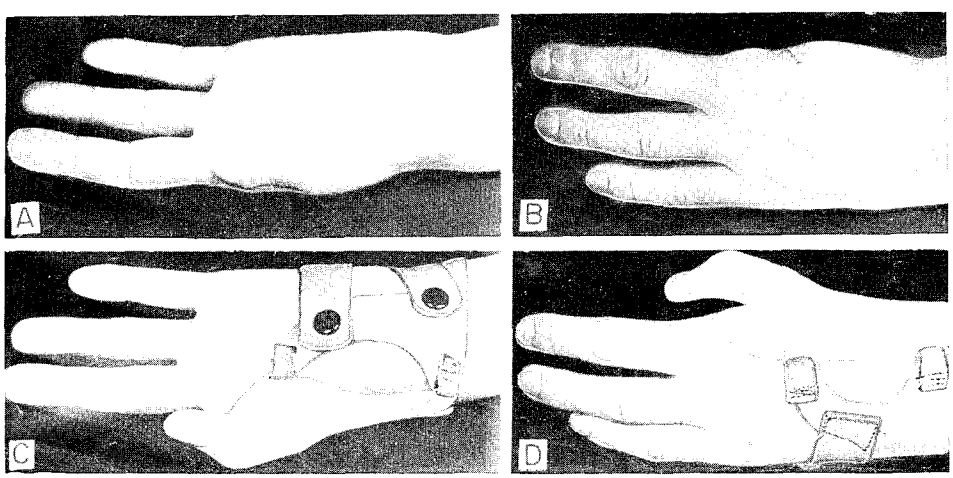



*Figure 177. Prosthesis for thumb. A. Palmar view of hand with missing thumb and index finger. B. Dorsal view. C. Palmar view of prosthesis in use. Note roughness of thumbtip, achieved by latex pad, to prevent slipperiness. D. Dorsal view.*

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CHAPTER XII

# Hand Surgery at O'Reilly General Hospital

*George S. Phalen, M. D.**

## ADMINISTRATIVE MANAGEMENT

Patients with hand injuries who were ambulatory and did not require emergency medical or surgical treatment were sent first to the admission section at O'Reilly General Hospital where a history was written, a physical examination made, and a hand consultation requested. Each case was reviewed jointly by a plastic, an orthopedic, and a neurosurgeon and a plan of treatment formulated. The proposed plan was recorded in detail on the chart. The patient was then transferred to the particular surgical section on which the first phase of treatment would be instituted.

The plastic section was responsible for the application of skin grafts and pedicle flaps and for the performance of some of the more complicated strictly plastic procedures such as interdigitation and Z-plasty. Neurosurgeons carried out operative procedures on nerves proximal to the wrist. Orthopedic surgeons performed all bone and tendon surgery and were responsible for nerve lesions distal to the wrist. They also performed simpler plastic procedures such as split thickness skin grafts, excision of scars, and reamputations.

Whenever it seemed desirable, the orthopedic surgeon assisted the plastic surgeon or the neurosurgeon at operation. He always shared in the procedure when bone or tendon surgery was performed at the same time that plastic surgery or neurosurgery was carried out.

By December 1945, five surgeons on the orthopedic section were qualified as hand surgeons; four of these were orthopedic surgeons and the other a general surgeon. Other members of the orthopedic staff operated under the supervision of these five men.

This administrative routine obviated the delay usually incurred by obtaining separate consultations from the plastic, orthopedic, and neurosurgical sections and permitted prompt institution of treatment. It had the additional advantage of providing for full discussion of each case by all the surgical specialists concerned in the treatment of each patient.

From the time of its designation as a hand center, O'Reilly General Hospital had at least 500 patients with hand injuries under treatment at all times, and by December 1945 more than 2,000 such injuries had been treated. Operations averaged 50 per week, more than half of the total number being performed by orthopedic surgeons.

*Assistant Professor in Orthopedic Surgery, Frank E. Bunts Educational Institute, Cleveland. Formerly Lt. Colonel, MC, AUS.

## QUALIFICATIONS AND TRAINING OF PERSONNEL

In January 1945 no surgeons on the O'Reilly General Hospital staff were specially trained in hand surgery. The chief of the surgical service, however, and the chiefs of the plastic, neurosurgical, and orthopedic services became greatly interested in the problem. The visits of the Civilian Consultant in Hand Surgery to the hospital in February and in August 1945 stimulated interest among other surgeons on the hospital staff and were of great help to those responsible for surgery in this special field.

## RECONSTRUCTION

### Initial Management

Primary efforts were directed toward putting the hand into position of function by proper splinting, then mobilizing it by the institution of physical and occupational therapy. A plan for surgical correction of the injury was outlined soon after the patient was admitted, but often it was necessary to modify this after the hand had been subjected to a period of supervised mobilization. In many instances surgery previously thought necessary was found no longer to be indicated.

Any infection present was eradicated as soon as possible by curettement of sinuses, removal of foreign bodies, or sequestrectomies. Little difficulty was experienced in securing prompt healing of draining hand wounds. Osteomyelitis involving the carpus, however, was much more difficult to cure.

The majority of hand injuries had already been immobilized too long and all casts or rigid splints were removed soon after the patient was admitted. A few, however, especially those with involvement of the carpal bones and the wrist joint, required a further immobilization period.

Finger and hand splints developed and recommended by the Civilian Consultant, Dr. Sterling Bunnell, were found to be very satisfactory. His spring cock-up splint was particularly effective in relieving flexion contractures of the wrist. The volar flexion traction splint designed in the hospital brace shop was used to mobilize metacarpophalangeal joints and relieve adduction contracture of the thumb (Fig. 178).

Occupational and physical therapy greatly aided in mobilization of stiff hands. Bunnell's recommendations were followed as closely as possible. Sending the patient home on furlough, where he could perform some type of work in which he was really interested, frequently resulted in remarkable improvement.

### Technical Procedures

*Skin Replacement.* Before attempting any reconstructive surgery on the bones, joints, nerves, or tendons of the hand, replacement of deforming or ad-

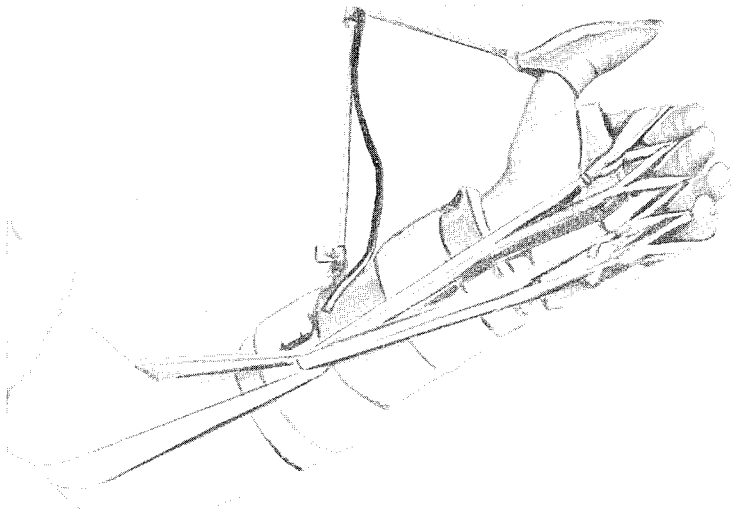


*Figure 178. Mobilizing splint originated at O'Reilly General Hospital. The elastics draw the thumb into extension and the proximal finger joints into flexion.*

herent cicatrix with adequate skin was essential. Pedicle flaps were usually employed, although occasionally, in a case in which a finger had to be sacrificed, the digit was filleted (the bone removed) and the remaining skin, with its blood and nerve supply preserved, turned down over the defect left by excision of a scar. Care had to be taken not to damage the digital nerves and not to constrict the circulation to the filleted finger. To smooth out the base of the flap it was almost always necessary to perform a minor plastic procedure 3 or 4 weeks after the first operation. When any tendon surgery beneath the scarred area on a hand was contemplated, it was much more satisfactory to replace the scar with a pedicle flap or a tubed pedicle graft than to substitute a filleted finger flap. Adipose tissue of a pedicle graft provided an excellent gliding bed for tendons.

*Capsulotomy.* This was found to be an extremely satisfactory operation on the metacarpophalangeal joints, and was frequently performed in combination with tendolysis of the extensor tendons. When the extensor tendons were contracted or bound down in scar tissue a capsulotomy alone would not restore any degree of satisfactory motion to a metacarpophalangeal joint. After release of the extensor tendons, however, it was frequently found that capsulotomy was not necessary to secure full flexion in such a joint.

## Bone Injuries

Among the patients on the orthopedic service at O'Reilly General Hospital injuries involving the bones of the wrist and hand were relatively uncom-

mon until the installation became a plastic and hand center in the early part of 1945. After that time there was a steady increase in the number of admissions for such injuries. Eventually about 80 percent of the 1,200 patients in the orthopedic service presented hand problems; at least 75 percent of these were fractures involving the wrist or hand.

Since almost all of these fractures were the result of perforating or penetrating wounds, the accompanying damage to the adjacent soft parts, including tendons, muscles, and nerves, was often very severe and produced disability of much greater degree than that which would be anticipated from the fracture alone. Because of the intricate anatomic structure of the hand, a small penetrating wound usually produced a much more serious and crippling disability in this region than in any other part of the body.

The great majority of patients admitted for further treatment of fractures of the wrist or hand presented fractures which were already healed. Fractures about the wrist might require a period of further immobilization in a plaster cast, but those in the hand were usually well healed by the time the patient reached the hospital, that is, about 6 to 12 weeks after the injury. As a rule, these fractures healed quite readily, and associated infection was usually easy to eradicate or control. In only a few was it necessary to drain an abscess, curette a sinus, or remove a sequestrum or foreign body.

Generally fractures had been immobilized too long, and furthermore, the entire hand was frequently immobilized unnecessarily in the treatment of a fractured bone involving only a single digit. Unduly prolonged and extensive immobilization proved to be the most frequent single factor in the production of excessive disability.

Since these fractures were already 2 to 3 months old when the patients were first seen in a general hospital, treatment usually resolved itself into rehabilitation or reconstruction.

*Fractures of the Distal Radius.* Nonunion was uncommon in fractures of the distal end of the radius. When seen, articular surface of the bone was usually involved, with the production of varying degrees of joint irregularity, limitation of motion, and traumatic arthritis. The majority of these fractures had been properly reduced, and, except in the occasional instance in which there had been considerable loss of bone, residual deformity was minimal. In these cases, however, there was a great tendency toward flexion contracture of the wrist, with inability to extend it beyond a neutral position. In most instances employment of physical therapy and the wearing of a spring cock-up splint relieved the contracture satisfactorily, though in two cases it was necessary to resort to a wedge osteotomy to correct the flexion deformity; the wrist joint was fused at the same time.

Patients with this type of fracture were given adequate physical and occupational therapy and had a trial period of active use long enough to ascertain whether or not radiocarpal arthritis was of sufficient severity to warrant

arthrodesis of the joint. Whether or not arthrodesis was to be performed was often left to the patient to decide. In several instances in which roentgenograms revealed rather marked disorganization of the wrist joint, but a fairly good range of painless movement was still possible, the patient believed he could carry on his civilian occupation satisfactorily with his disability. If a patient made his living working with his hands, a minimal amount of traumatic arthritis was often sufficiently incapacitating to warrant arthrodesis.

*Arthrodesis.* Arthrodesis of the wrist was performed in only 13 patients at O'Reilly General Hospital, representing not more than 5 percent of the number of wrist fractures observed. An arthrodesed wrist joint does not produce a great amount of disability, and the operation was strongly advised in all cases of limited, painful wrist motion. Although a bone graft was not always necessary, employment of a thin iliac graft hastened fusion, and wrists were found to be solid clinically as early as 3 or 4 weeks after operation, though immobilization was carried out in all cases for a minimum of 12 weeks. In 3 instances the distal end of the ulna was removed and a portion of the excised bone used as a small inlay graft across the resected wrist joint.

*Fractures of the Carpus.* Fractures involving the proximal row of carpal bones frequently accompanied others of the distal end of the radius. Such injury produced traumatic arthritis of the wrist joint itself. Fractures involving only the distal row of carpal bones seldom produced any disability insofar as the bones themselves and adjacent joints were concerned.

In a few instances eradication of infection in an extensively comminuted fracture of the carpus (Fig. 179) was quite difficult. In these several curettements and sequestrectomies were necessary before drainage could be checked. In general, damage to the overlying extensor and flexor tendons was much more important than the actual fracture of the carpus.

*Fractures of the Metacarpals.* Prolonged and unnecessary immobilization of the metacarpophalangeal joints in hands with fractures of the metacarpals, already mentioned, was the most important single cause of resultant disability. Stiffening of the metacarpophalangeal joints in extension invariably produced a severely disabled hand and as a rule required a prolonged period of hospitalization for rehabilitation.

Proper alinement of these fractures was quite important, since the dorsal angulation so commonly seen at the fracture site was likely to produce limitation of flexion at the metacarpophalangeal joint, as well as a prominent metacarpal head in the palm. Shortening of the bones, if not excessive, did not produce a great deal of disability, although there was usually some resultant limitation in flexion of both the involved and adjacent digits. In many instances osteotomy for correction of malalinement of these features was carried out. To ensure prompt union of the fracture a bone graft was usually performed at the same time. A very high percentage of nonunion was seen

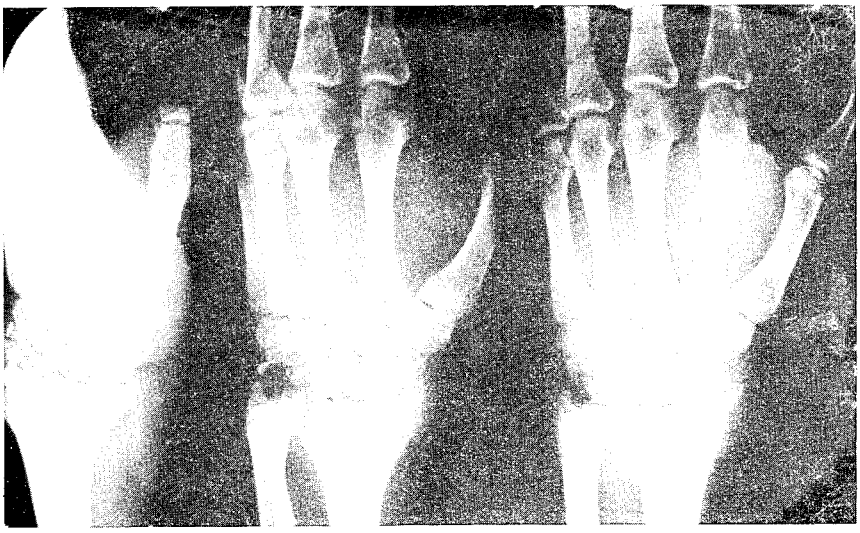


*Figure 179. Lateral, oblique, and anteroposterior roentgenograms showing an extensively comminuted compound fracture of the carpus and the distal radius. To obtain complete healing with ankylosis of the wrist joint, this type of fracture usually required prolonged immobilization.*

in metacarpal fractures, the cause in almost every instance being excessive loss of bone (Fig. 180).

A rather large number of metacarpal fractures were grafted. In cases involving considerable loss of bone tibial grafts were used at first. When only a small key graft was employed, small sections were removed from the ulna. Later, iliac bone was used almost exclusively. Bone from this source affords quite good stability and because it is more readily vascularized than tibial bone, healing was prompter when it was used. The employment of iliac bone removed the danger of fracture at the donor site.

Grafts were almost always applied as intermedullary grafts and attempt was made to restore the metacarpal to as nearly normal length as possible. The grafts were usually stable enough not to require internal fixation, though Kirschner wires were occasionally used to fix the grafted bone to the adjacent metacarpal. At first it was the policy to defer tendolysis of the extensor tendons and capsulotomy of the metacarpophalangeal joints until after the metacarpal fracture had united, following bone graft. Later, as experience increased, all of these procedures were carried out at the same time, and the excellent end results fully justified the practice. When the cast was applied after operation it did not immobilize the metacarpophalangeal joints and their early motion was encouraged. The involved metacarpophalangeal joint, however, was not forced until the metacarpal fracture had healed.

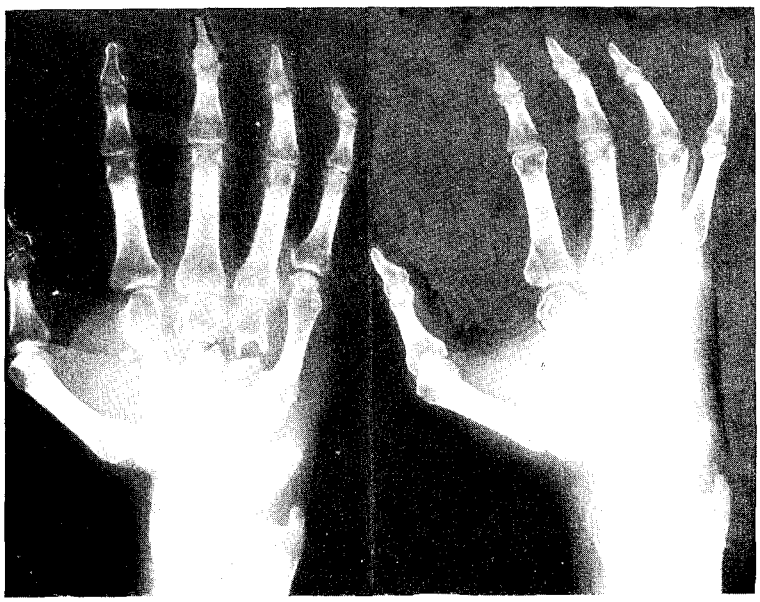


*Figure 180. Anteroposterior and oblique roentgenograms showing nonunion of compound fractures of the second, third, and fourth metacarpals. The nonunion was the result of extensive loss of bone substance. Since this soldier had no pain at these fracture sites and was able to make a satisfactory fist, bone grafting was not advised.*

In an occasional case of metacarpal nonunion there was sufficient range of painless motion at the site of the lesion for the patient to make quite a satisfactory fist. Some of the patients with these injuries, therefore, refused operation and a bone grafting procedure was not done because it was felt that this would not materially reduce their disability (Fig. 180).

For lesions of the proximal and middle phalanges bone grafting was seldom necessary. For crossing of the fingers on flexion as the result of nonunion, rotation osteotomies were sometimes indicated. When the operation was performed a small intermedullary graft was usually employed to guarantee union.

In cases in which a fracture involved the head of the metacarpal arthroplasties of the metacarpophalangeal joints were moderately successful in the experience at O'Reilly General Hospital. When the articular surface of the proximal phalanx was also involved the results of arthroplasty were not as satisfactory. In some cases an acrylic cap was employed over the end of the metacarpal but this procedure was found to offer no advantages over the usual technique of arthroplasty with fascia lata.

*Fracture of the Phalanges.* Comminuted fractures of the phalanges were practically always accompanied by some limitation of motion in the adjacent interphalangeal joints. Mobilization of these joints was a difficult task and

operative intervention to restore a more normal range of motion did not prove very satisfactory. Unless amputation of the finger was requested by the patient it was the policy to perform arthrodeses of the proximal and distal interphalangeal joints in the position of function. With only a single finger involved and the balance of the hand practically normal, the patient usually chose amputation of the finger to a flexed stiff digit. This was especially true of soldiers who planned to earn their livelihood with their hands in civil life.

## Nerve Injuries

Highly satisfactory results were obtained in neurorrhaphies of the digital nerves. Since a finger without feeling is very little better, and sometimes worse than no finger at all, restoration of sensation to an anesthetic finger was regarded as of prime importance. No nerve grafting procedures were done. In the patient in whom a little sensation remained in the finger but a tender neuroma was present along the course of the digital nerve, resection of the neuroma with suture of the nerve was the procedure of choice. Neurolysis of these nerves practically always resulted in persistence of the neuroma and of the "hot spot" in the patient's hand. Removal of painful neuromas from the palm permitted the patient to use his hand more freely, and thus enabled him better to mobilize his fingers.

## Tendon Injuries

Repairs and grafts of the extensor tendons were for the most part quite satisfactory. To provide good gliding surface a small strip of fascia removed from the forearm or thigh was often placed beneath the extensor tendons. It was sometimes possible to mobilize a satisfactory layer of fascia from the tissues immediately adjacent and to swing it beneath the extensor tendons in the scarred area.

Repairs and grafts of the flexor tendons were much less satisfactory. To obtain a fairly complete range of motion in the finger a secondary tendolysis was required in practically all grafts. As is usual, the end result of any tendon operation depended upon the desire of the patient to secure a good result and his willingness and eagerness to cooperate in postoperative treatment. This was especially true in operations upon the flexor tendons. The end results in Negro patients with low thresholds of pain were universally poor, the enlisted white man showed fair results, while those in white officers were most satisfactory because of the cooperation of the latter.

## Amputations

With the ending of the war, elective amputations became much more frequent. The soldier-patient was no longer willing or anxious to remain in the

hospital for a prolonged period and perhaps undergo several operations in order to restore nearly normal function to a damaged digit. The loss of any single digit, except the thumb, was not regarded as too serious insofar as actual function of the hand was concerned, especially if the entire hand, with the exception of the injured digit, was nearly normal.

The criteria for elective amputation of a finger were as follows:

1. Severance of, or severe damage to, both flexor and extensor tendons, with or without associated fracture or nonunion of the respective phalanges or metacarpals.

2. Damage to either flexor or extensor tendons which was not readily reparable, provided the balance of the hand was nearly normal. This indication applied especially to injury of extensor tendons overlying the proximal phalanx.

3. Damage to the proximal interphalangeal joint with resultant pain and limitation of motion. Arthroplasty of this joint was not satisfactory, and unless the patient wished an arthrodesis of the joint in a functional flexed position, amputation of the finger through this joint was the only solution.

4. Severe damage to the metacarpal bone, with loss of the distal end, including the head and articular surface.

5. Circulatory insufficiency.

### Reconstruction and Transplantation of Digits

The reconstruction of digits was limited entirely to the thumb. Tube pedicle grafts, with insertion of either iliac or tibial bone, were used in making these. Multiple operative procedures were required and were fraught with complications. In a few cases the grafts fractured or became sequestrated. Trophic ulcers on the end of the new thumb were not uncommon because of the insensitivity of the newly made digit. The end results did not prove to be too successful and it was thought doubtful whether the most satisfactory result provided much better function than the wearing of an adequate prosthesis.

In one case an index finger was transplanted to the stump of a thumb with preservation of the nerve and blood supply of the index finger, and the result was quite satisfactory. In this particular case the index finger was to be sacrificed anyway due to tendon damage and loss of the second metacarpal, but the results of such an operation are hardly certain enough to warrant the sacrifice of a normal index finger to replace a thumb.

## PROSTHETIC APPLIANCES

Since O'Reilly General Hospital was not an amputation center all patients in need of prosthetic appliances for their hands were sent to the amputation center nearest their homes. A patient admitted to the plastic section who had had an amputation of all the fingers and the tip of the thumb on the right hand,

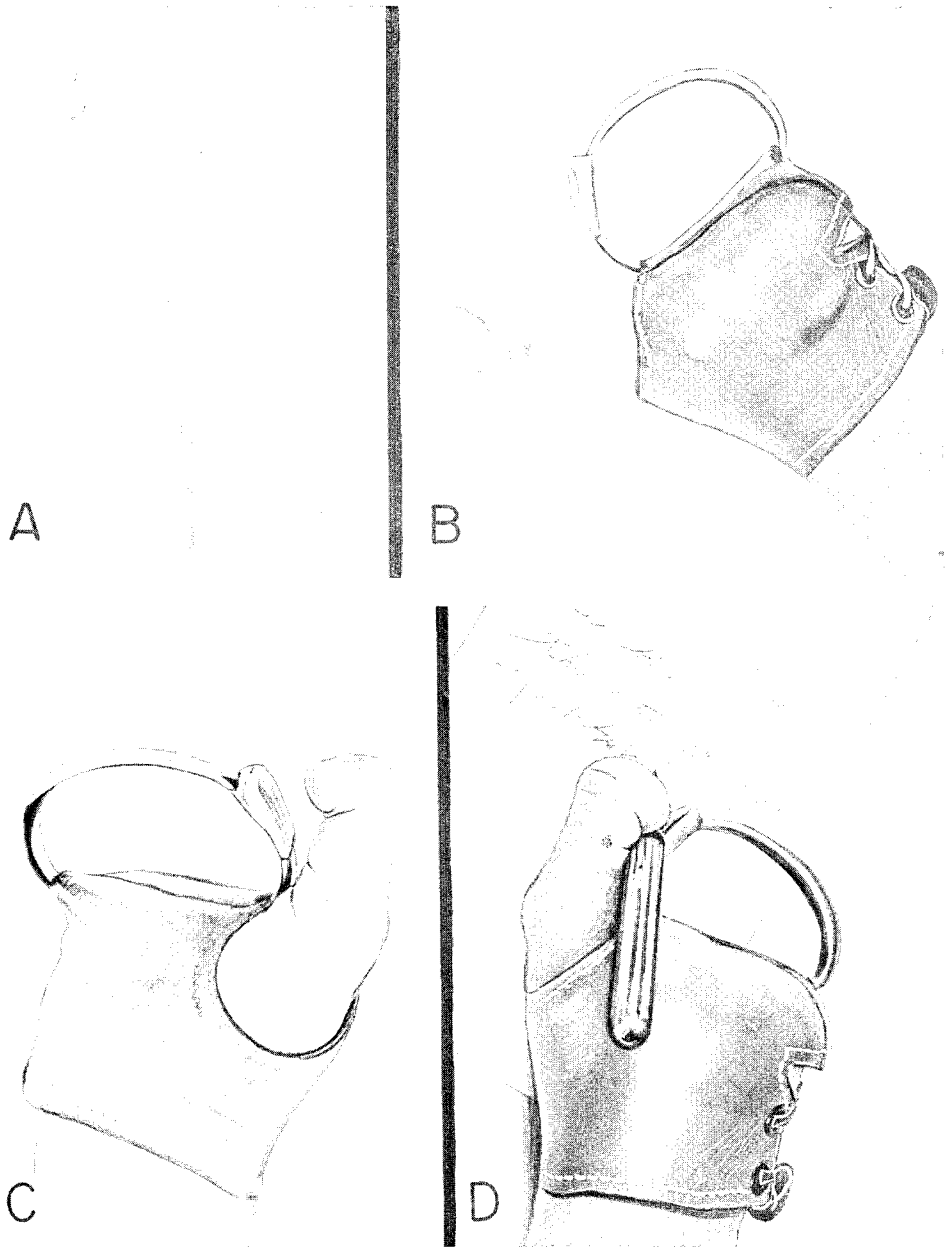



*Figure 181. Prosthesis devised by a patient who had lost all digits except the thumb. A. Extent of injury. B and C. Views of prosthesis. D. Patient writing with aid of prosthesis, which proved particularly useful for this and other purposes.*

designed a very simple and useful prosthesis for this hand while hospitalized at Percy Jones General Hospital (Fig. 181). The curved metal bar on this prosthesis was especially useful in writing, since it balanced the hand much as do the flexed middle, ring, and little fingers in a normal hand.

CHAPTER XIII

# Hand Surgery at Valley Forge General Hospital

*Walter C. Graham, M. D.**

## ADMINISTRATION

After Valley Forge General Hospital became a plastic center, approximately 1,500 patients with injuries of the hand and forearm were admitted to it. Though they were assigned to the plastic surgery section, all were treated in consultation with the orthopedic service. Thus, evaluation of the injury and decision concerning future treatment was a joint responsibility.

Patients with hand injuries associated with certain types of nerve injuries were also treated on the plastic service. If injury involved a nerve of the hand or wrist, the patient was retained for treatment. If it was on a higher level in the forearm, or above the elbow, he was transferred to a neurosurgical center. Nerve suture in the hand or wrist was usually carried out on the orthopedic service but was occasionally done by the plastic surgeon at the time a flap was applied or some other plastic work performed. In numerous instances plastic and orthopedic surgeons operated together, thereby materially decreasing the number of operations necessary in individual patients.

During the last 6 months of 1945 casualties with hand injuries from overseas decreased greatly in number. Per contra, similar patients received from general hospitals in the Zone of Interior increased. In many a portion of the surgical work had already been carried out and only the surgery necessary to restore function remained to be achieved.

## PERSONNEL

The personnel of the plastic surgery service was for the most part composed of surgeons with extensive experience in general and plastic surgery. Many of them were assigned to the hospital for periods of 2 to 2½ years. The result was a well-coordinated and well-organized group, competent to perform a large amount of work of high quality. In addition to the application of innumerable split skin grafts, approximately 260 abdominal flaps and 40 local flaps were applied to the forearm and hand.

During the first 18 months orthopedic surgery on injured hands was done by 2 surgeons with broad training in general and traumatic surgery which particularly qualified them for this work. Thereafter some of the surgeons assigned were well trained in orthopedic surgery, while others required on-

*Orthopedic Surgeon. Formerly Lt. Colonel, MC, AUS.

service training in hand surgery against a background of experience in orthopedic or general surgery. Even well-trained surgeons cannot perform the detailed and specialized operations necessary in combat-incurred hand injuries without additional practice in this special field. Over a period of 2 years, orthopedic surgeons at Valley Forge General Hospital performed a total of 1,450 separate operations on injured hands, 80 percent of which were done during 1945.

The three visits paid to the hospital by the Civilian Consultant in Hand Surgery, Dr. Sterling Bunnell, were of great value to the experienced surgeons who constituted the staff responsible for hand injuries, and of even more value to the members of the staff whose experience was less extensive.

## RECONSTRUCTION PROBLEMS

A statistical analysis of surgery of the hand is seldom accurate. If reconstruction is undertaken in the most efficient manner, a number of different procedures will be performed in a single operation. This was the policy adopted at the Valley Forge General Hospital. From the beginning, as much of the reconstruction as possible was accomplished at a single stage, and as time passed it was found that more and more could be done at one time. Often bone grafts were placed, nerves sutured, and tendons freed or sutured at one operation. Tendolysis and nerve suture were carried out when an abdominal flap was applied. Occasionally, bone grafting and osteotomy were performed when a remote flap was attached. For these reasons differentiation of operations into various procedures is not accurate. But some discussion of the various procedures under individual headings will simplify presentation, though it should be borne in mind that in clinical practice such simplification is not in the best interests of the patient.

### Burns

After designation of Valley Forge General Hospital as a plastic center many casualties were received who had been severely burned. Practically all with extensive and multiple burns on the body had also burns of the forearms and hands. These injuries were as serious as any encountered.

Deformities of the fingers following burns were unpredictable, though the type was generally determined by the depth to which the soft tissues were damaged. Surface damage was never the entire problem; the deep structures were usually damaged also, and there was a tendency for contractures to form over long periods of time. The burn frequently extended into the joint surface, particularly the two distal joints of the fingers, destroying the articular surface as well as the tendons and the overlying soft tissue. Damage to the palmar side of the hand and to the flexor mechanism was seldom as severe as that to the dorsal aspect.

To promote healing by split skin grafting was the first problem though later it might be necessary to remove the graft and apply a flap, particularly if work on the extensor tendons was necessary. When damage to the joint surface of the interphalangeal joints was so severe that restoration of articular function obviously could not be accomplished, arthrodeses were performed. In injuries of this kind another problem had to be solved, namely the loss of extensor mechanism while a strong flexor tendon remained, with a resulting tendency for the joint to be pulled into flexion. Correction was occasionally accomplished by transplantation of a portion of the flexor tendon to the dorsum of the hand, to limit the flexor pull and balance the direction of pull.

## Cold Injuries

A few patients had injuries which were the result of exposure to cold, chiefly in airplane accidents. One casualty in this group had lost all the fingers and the thumb on one hand; the other had sustained the same injuries on both hands (Figs. 182 and 183). In each patient the same procedures were carried out as follows: The hand was clefted, so that the first metacarpal could oppose the third; to secure added length the second metacarpal was partially resected and transplanted to the distal end of the first; a local flap from the dorsum of the hand was turned through the cleft, to deepen it and to keep it from creeping out toward the end of the metacarpal. In both patients functioning hands were achieved, a result which was even more important in one than in the other because the casualty was also totally blind.

## Skin Repair and Replacement

Certain preliminary steps usually necessary before reconstructive surgery could be carried out included the clearing up of draining, granulating and infected areas, which might require sequestrectomy or the removal of foreign bodies, and the excision of scar tissue, which usually made a third procedure necessary—plastic surgery in the form of local or remote flaps (Fig. 184).[1]

*Flap Formation.* Whenever a wound extended completely through the hand or forearm, which frequently occurred, flaps for both the dorsal and the volar surfaces were required. A local flap was sometimes used to close a portion of the hand at the expense of another area; a single remote flap was then used instead of separate flaps for the dorsal and volar surfaces. Scar tissue was excised and the excision carried down to normal tissue whenever possible, after which an abdominal flap was raised and turned upward for the radial,

[1] As a matter of convenience, certain illustrations are referred to under certain headings. It should be noted, however, that in practically all of the cases depicted, multiple operations of various kinds were performed, multiplicity of surgery being characteristic of the injuries treated on the hand service at Valley Forge General Hospital as well as on similar services of other general hospitals in the Zone of Interior.

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*Figure 182.*

*Figure 182. A and B. Clinical and roentgenologic appearance of hands frozen in an airplane crash in which the oxygen supply was knocked out and patient lost both gloves while unconscious. All fingers and thumb of left hand were amputated at the level of the metacarpophalangeal joints. There was marked scarring at the end of the stumps, with considerable contracture. All the fingers were lost on the right hand above the proximal phalanx but the thumb was still present. When the patient arrived at Valley Forge General Hospital the left hand was almost completely healed but there was still drainage from the tips of all of the fingers of the right hand. The wounds were closed after sequestrectomy. C. Appearance of left hand after abdominal flap preparatory to clefting. D–F. Clinical and roentgenologic end results of surgery. Reconstruction was begun 4 months after the placing of the abdominal flap and 1 year after the injury. The proximal two-thirds of the second metacarpal of the left hand was resected, with the exception of the base, and transplanted to the distal third of the tip of the first metacarpal. The transplanted portion of the second metacarpal was allowed to unite with the first metacarpal. Six weeks later the second stage of the cleft operation was performed. It included splitting the hand down to the base of the second metacarpal, cutting away considerable redundant tissue, turning the flap from the dorsum to form the base of the cleft, and suturing it to the palmar side of the hand. The purpose of this procedure was to prevent the cleft from closing down, as it would have done if a single split graft had been applied. The exposed area was covered by a graft from the thigh. When the patient was last seen he had an excellently functioning claw-type of hand in which he could hold objects. He was able to spread the thumb from the hand for almost an inch and could perform many duties with the reconstructed extremity.*




*Figure 183. A–C. Clinical and roentgenologic appearance of frozen hands and face. This officer, who was in the nose of a B–17 which was severely damaged by enemy action, lay unconscious in the open nose of the bomber for a long period. As a result he sustained total loss of vision and loss of the thumbs and all the fingers on both hands. Sensation in the hands was still present. D–F. Clinical results following surgery. On the left hand the second metacarpal, which was of full length, was resected for the proximal two-thirds. The distal third was transplanted onto the first metacarpal. Six weeks later a cleft was opened, considerable fatty tissue and muscle being excised to form it. A local dorsal flap was turned through the cleft and sutured onto the palm of the hand. The surfaces still exposed were covered with a split skin graft. Four months later a similar procedure was carried out on the right hand except that the second metacarpal was transplanted to lengthen the first. On this hand the distal third of the second metacarpal was lost and the bone was therefore of the same length as the first metacarpal. As a result of the formation of the bilateral cleft, the patient became able to use his hands, write, feed himself, and cut his food with a knife and fork. He was not able to perform finer motions, such as buttoning his clothes, but he learned to use the claw with considerable facility. In this patient the great value of the operation was to maintain sensation, which is so necessary when vision has been lost.*

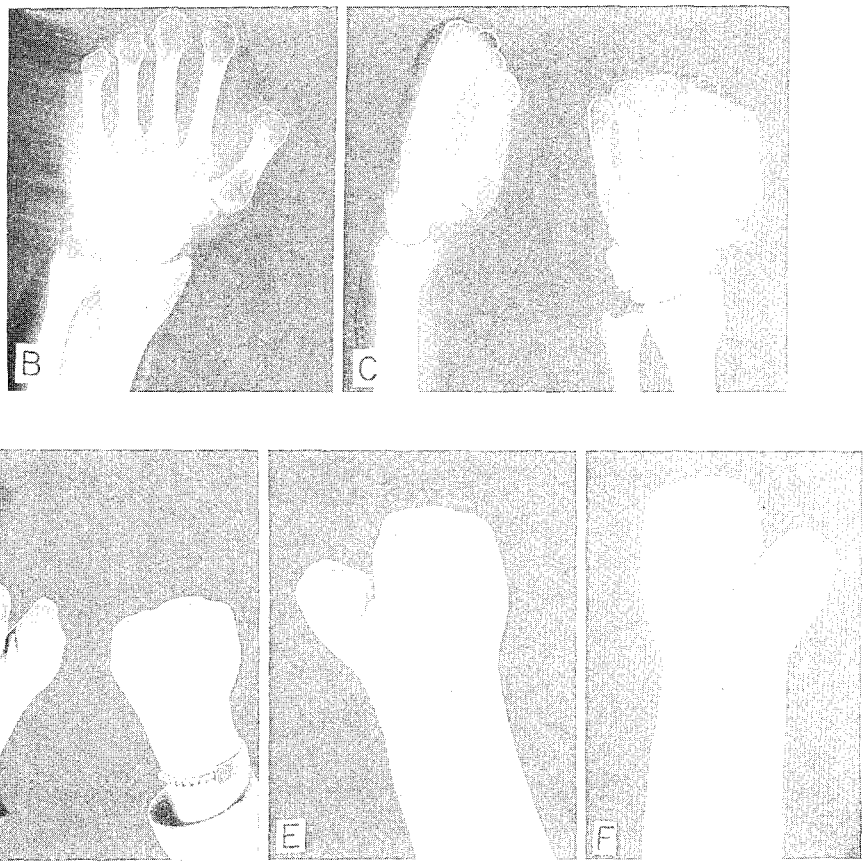



*Figure 183*—Continued.

and downward for the ulnar side of the hand. Abdominal flaps were usually taken from the lower portion of the abdomen near the anterior spine of the ilium where the skin is pliable and fat is sparse. At the end of 18 to 21 days the flap was detached and the other border sutured into place. It was the policy to wait from 4 to 6 weeks after this operation before undertaking any surgery on the deep structures.

Flaps which had been applied overseas were in many instances satisfactory, but in some, insufficient time had been allowed for an osteomyelitis to heal and examination revealed drainage from beneath the flap. In these it was necessary to perform a sequestrectomy, then excise considerable scar tissue and thin the flap before healing could be expected.

Numerous patients were received with split skin grafts which had been applied overseas. These were usually well healed. The location of the graft determined whether or not it need be excised and replaced by a flap. If nerve,

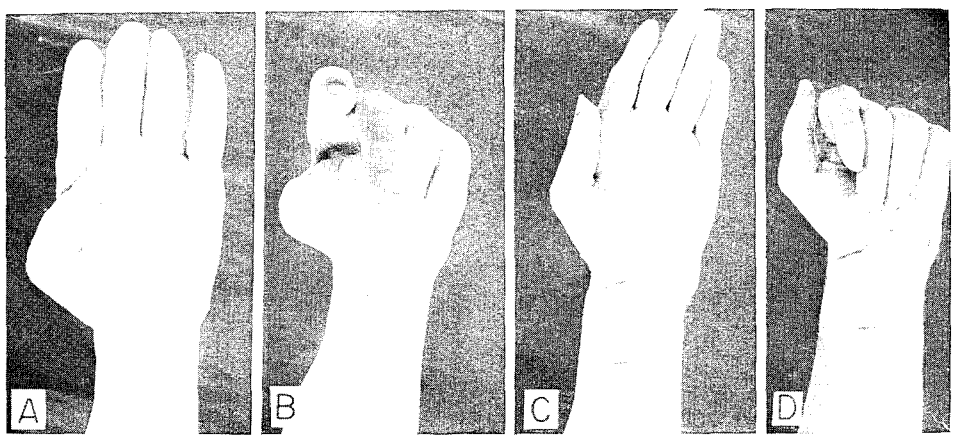



*Figure 184. A and B. Severe injury from shell fragment to volar surface of forearm, about 2 inches above wrist with complete severance of median nerve and of long flexor tendon to thumb, as well as injury to flexors of fingers. The thumb was pulled into the palm and any attempt to flex the fingers was blocked by the scar contracture of the flexor tendon. C and D. End results following surgery. First stage consisted of excision of scar from forearm and application of abdominal flap. Later forearm was explored and the median nerve isolated and sutured. The large amount of scar tissue present was excised. Continuity of flexor tendon of thumb was re-established and flexor tendons of fingers freed from scar tissue. On discharge patient had had return of median nerve sensation to tip of finger, full range of extension and flexion of thumb, and complete flexion of fingers. There had been no return of stereognosis but there had been gradual improvement in sensation.*

tendon, or bone repair were necessary, the graft was excised and replaced with a flap so that work deep in the hand could be carried out through healthy tissue. It was a general observation that hands to which split skin grafts had been applied soon after wounding healed with much less scarring than those in which wounds had been allowed to granulate. The softness and pliability of the tissues were always greatly affected by the period over which drainage continued.

## Nerve Repair

Although the extent of damage determined the procedures to be carried out in reconstruction, the first objective in repair of any hand in which sensation had been lost was to restore this. To that end nerves were sutured on 196 occasions and nerve grafts performed 24 times.

Nerves were approximated whenever possible by end-to-end anastomosis (Fig. 185). In suturing the ulnar nerve special care was taken to avoid rotating the proximal and distal ends. In the absence of this precaution, motor branches can grow into sensory slips and vice versa.

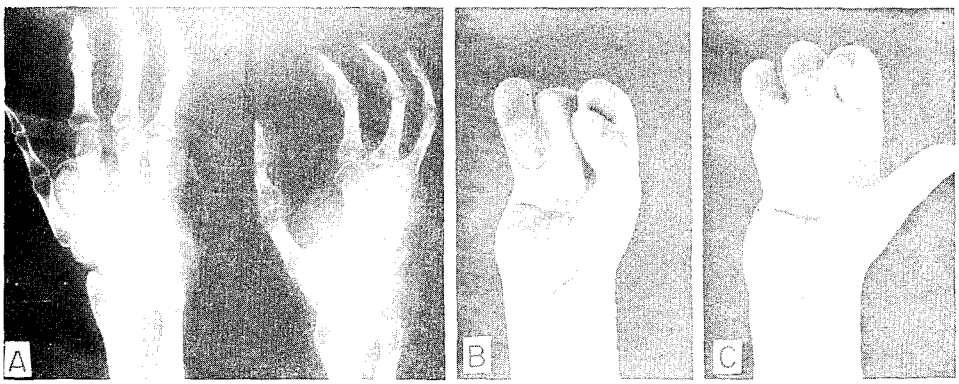



*Figure 185. A–C. Roentgenologic and clinical end results of surgery for shell fragment wound from mortar fire resulting in traumatic amputation of the right little finger and the fifth metacarpal bone. There was marked scarring on the volar surface of the hand. Before the patient was admitted a skin flap had been applied to replace the scar on the palm. He had complete ulnar and medial nerve paralysis to the remaining fingers. Sensation in the thumb was normal. Reconstruction consisted of (1) exploration of the palm of the hand and suture of the median and ulnar nerve slips, and (2) tendolysis, the flexor tendons of the amputated finger being freed from the scar, which was preventing the other fingers from closing. When the patient was discharged he had almost complete flexion and extension of all the fingers, with complete return of sensation to the remaining fingers. Function was excellent.*

At Valley Forge General Hospital experience with suture of the motor nerves of the hand was limited. If the wound was near the base of the hand and had resulted in severance of the motor branch of the ulnar nerve at this point, it was impossible to suture it because the divisions are so fine. If the injury was above the wrist, the motor branches were approximated, but results from the standpoint of return of function were minimal.

If nerve suture was impossible and a finger or a portion of the hand missing, the nerves which formerly supplied sensation to the missing parts were dissected out and used as grafts. Otherwise, the graft was usually secured from the sural nerve. When the damaged nerve was in the distal part of the forearm and the gap such that the ends could not be brought together, two or three thicknesses of the sural nerve were used. Both median and ulnar nerves were successfully grafted in this manner.

With the exceptions mentioned, restoration of sensation following nerve suture and nerve graft was extremely gratifying. Almost normal sensation was likely to return within the expected time, about 1 mm. per day, depending upon the distance of the injury from the tip of the finger. Refined sensory function returned more slowly. If the suture or graft had to be carried out in a densely cicatricized area, return of function was slower and less complete than when the site of the repair was more favorable.

## Bone Injuries

Extensive damage to bony structures caused by shell fragments and bullet wounds was sometimes almost incredible. Loss of bony continuity, malunion and nonunion of bones of the hand, wrist, and forearm, were frequent. These bony injuries had to be repaired and corrected before tendon surgery was undertaken (Figs. 186–190).

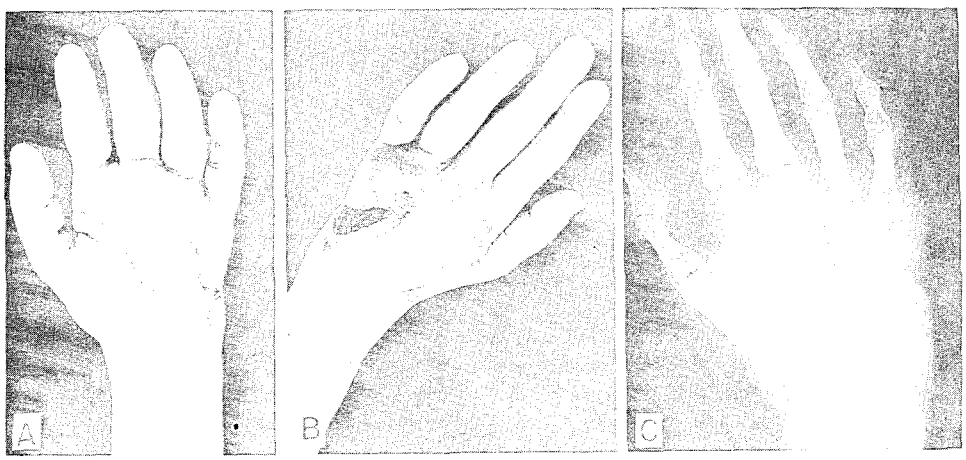



*Figure 186. A–C. Clinical and roentgenologic appearance of left hand following shell fragment wound which resulted in destruction of soft tissue on the ulnar border and fractures of the fourth and fifth metacarpals with great loss of bony substance. The little finger was anesthetic and had no motor function. The flexor tendons to the ring finger were present, but could not function because loss of bony substance prevented stabilization of the finger. D–F. End results of surgery. The proximal phalanx of the amputated little finger was used as a bone graft to fill in the defect in the fourth metacarpal. At the same operation, an abdominal flap was applied to fill in the soft tissue defect on the ulnar side of the hand. Three-and-a-half months later an extensor tendon graft was placed to the ring finger, the communis tendon being used for motor power. Following this procedure the patient complained of inability to stabilize the finger, which had no muscle power to move it in adduction or abduction. The sublimis muscle to the little finger was therefore grafted and fixed to the radial side of the base of the proximal phalanx. These procedures corrected the instability of which he had previously complained. He had 70 degree of flexion at the metacarpophalangeal joint and full extension. As a result of loss of intrinsic control there was a residual moderate flexion contracture of the two distal joints.*

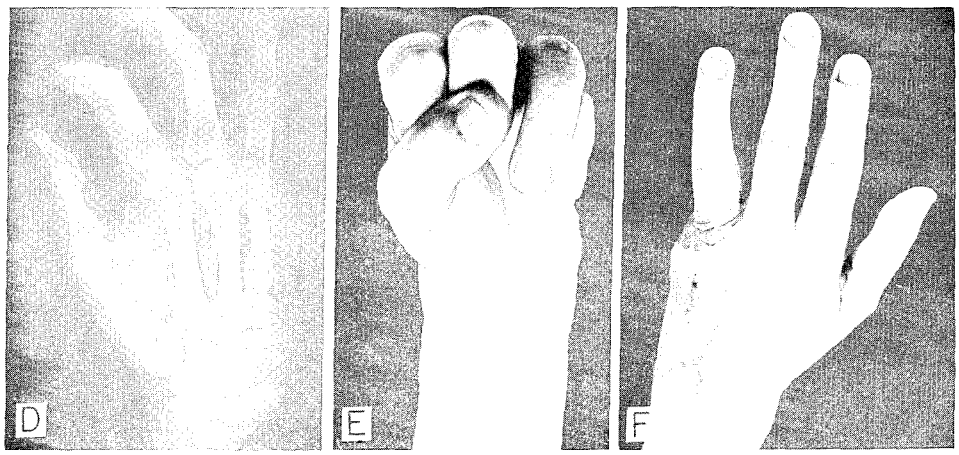



*Figure 186*—Continued.

The problem of malalinement was most frequently encountered in fractures of the metacarpal bones in which the head of the metacarpal had dropped into the palm and, as a result, the direction of the pull of muscles and tendons was altered and flexion at the proximal joints entirely blocked. In instances of this sort the malalinement had to be corrected and the head of the metacarpal elevated into its normal position. Capsulotomy (Figs. 187 and 190) was frequently necessary before the distal fragment could be restored to its proper position.

*Bone Grafts.* Defects in the bones were compensated for by bone grafts. The tibia was originally used as the source of the grafts applied in defects of the metacarpals, but the hardness of its cortex made it extremely difficult to work with. The ilium was therefore substituted for grafts used in both metacarpals and phalanges and was found to be entirely satisfactory. The usual technique was to cut the graft from the crest of the ilium, shape it to fit the defect, and to fix it in place with Kirschner wires. If continuity of two adjacent metacarpals had been destroyed and the interosseous muscles damaged, a single graft was used to replace the defect in the two bones, the piece removed from the ilium being wider than usual. If the intrinsic muscles were still functioning, however, and there was sufficient muscle tissue to bring between single grafts, each bone was grafted individually.

In these bony defects the metacarpophalangeal joint practically always was found fixed in complete hyperextension and could not be flexed to its normal position, necessitating cutting away the collateral ligaments and the joint capsule. On many occasions the anterior portion of the capsule was adherent to the articular surface and had to be stripped free before the joint functioned normally. When in addition to the distal half or third of the shaft the head of the articular surface of the metacarpal had been lost, a metatarsal bone

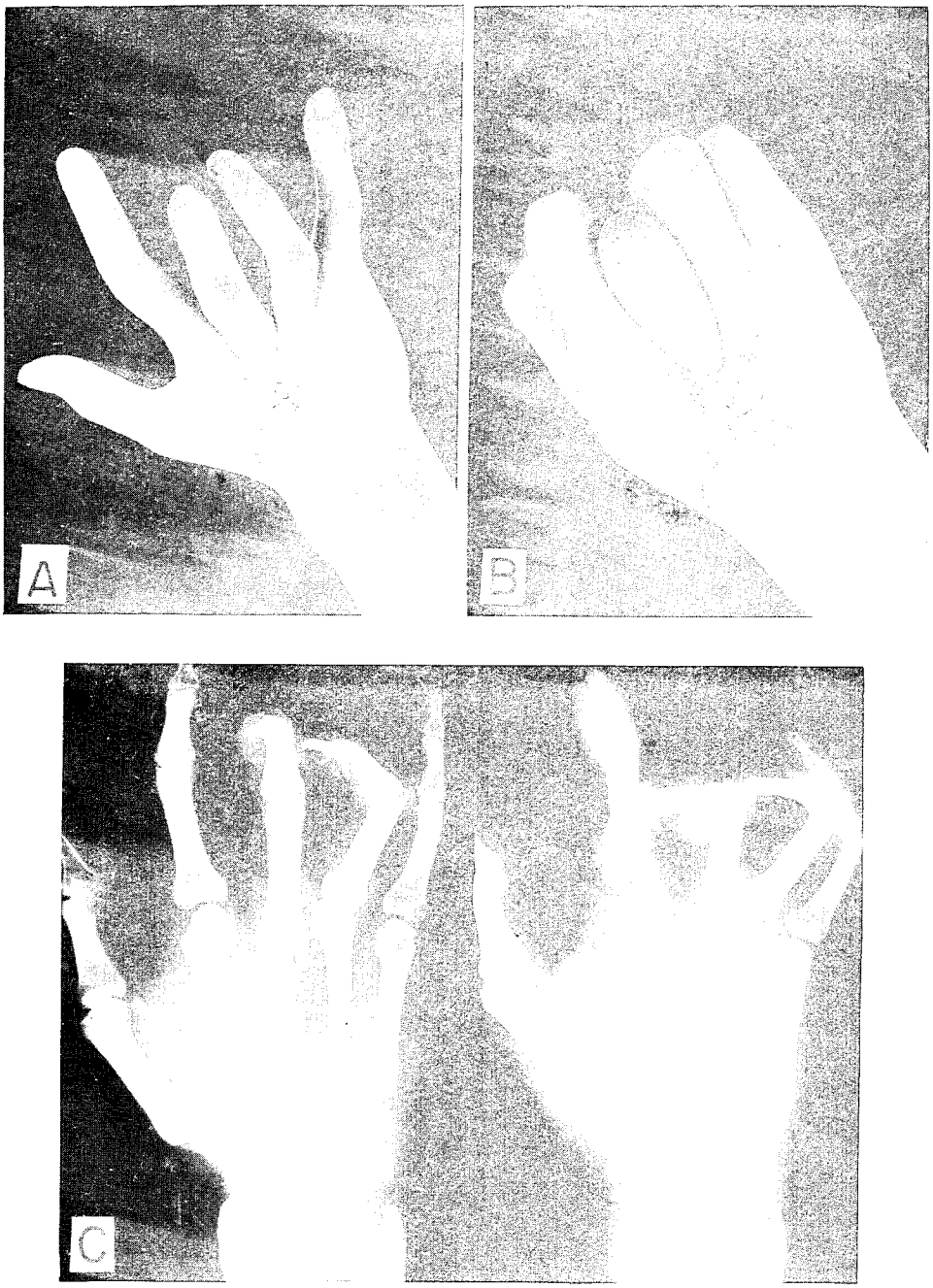



*Figure 187.*

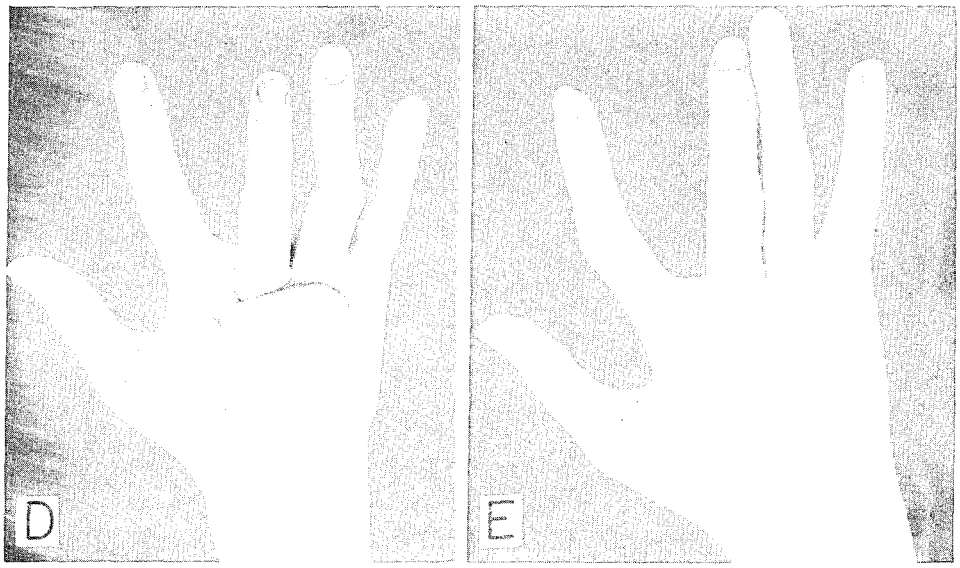



*Figure 187. A–C. Clinical and roentgenologic appearance of right hand following injury by fragments of hand grenade. The index and little fingers had practically normal range of motion. The extensor tendons to the middle finger were caught in the stellate dorsal scar, and the metacarpophalangeal joint could not be flexed because of cicatricial contracture of the intrinsic muscles. The head and distal third of the shaft of the fourth metacarpal had been destroyed and the extensor tendon of this finger was missing. The intrinsic muscles on the radial side of this finger were also destroyed. Except in the area of the dorsal scar sensation was normal throughout the hand. D. Appearance of hand after complete excision of dorsal scar and application of abdominal flap. E. Final clinical appearance of hand. Following the plastic surgery described, a bone graft was applied to the third metacarpal bone, the fifth metatarsal being used as the source of the graft. The articular surface was saved to form the proximal surface of the metacarpophalangeal joint of the middle finger. At the same time an extensor tendon graft was done to reestablish the extensor communis tendon to the ring finger. The patient had excellent motion in the newly formed joint and the only remaining deformity was caused by loss of intrinsic control which normally would permit him to flex the proximal joint of the middle and ring fingers and extend the distal joints. Three months later capsulotomy was performed at the metacarpophalangeal joint of the ring finger. The sublimis tendon was then freed at its distal attachment and transplanted through the lumbrical canal; it was attached to the extensor sleeve and the extensor tendon of the ring finger. The sublimis of the little finger was also removed at its distal attachment and threaded up the distal side of the ring finger, then attached to the extensor sleeve. When the patient was discharged he had active motion of the metacarpophalangeal joint of the ring finger through a 90-degree range. Flexion was possible to about 110 degrees and there was full extension of the two distal joints. The extensor tendon graft permitted full extension of the proximal joint of the finger.*

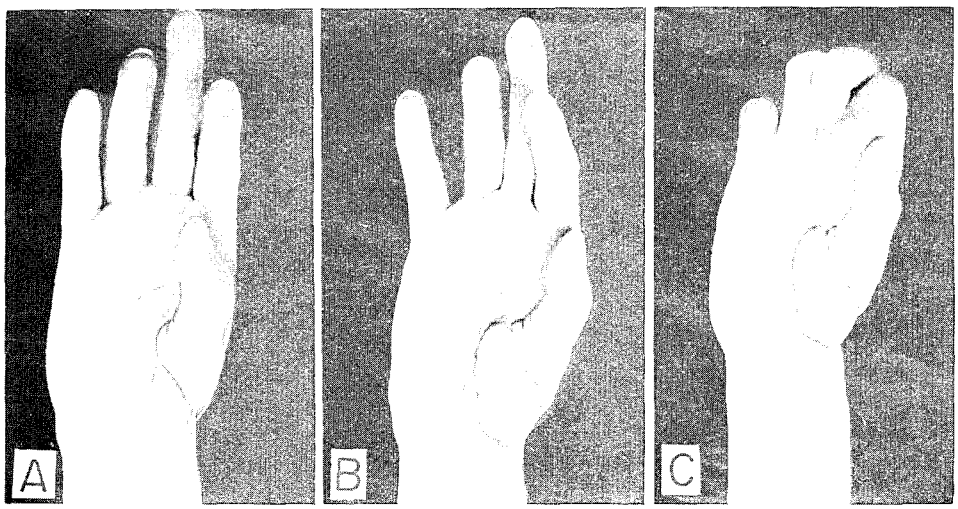



*Figure 188. A. Severe crushing injury of the radial aspect of right hand, with comminution of the first metacarpal and severance of the flexor tendon to the thumb. There was loss of sensation in the index finger and the radial side of the thumb. B and C. End results of surgery. The scar tissue was excised on the plastic service and an abdominal flap applied. The second operation included the application of a bone graft to the first metacarpal with fixation of the thumb in position for opposition. At a third-stage operation a flexor tendon graft to the thumb was carried out and the cutaneous nerve to the index finger and the thumb was sutured. When the patient was discharged he had a flexor and extensor function of the thumb which was so fixed that it could oppose the fingers. At this time there was returning sensation in the thumb and index finger.*

was transplanted to fill in the defect, the articular surface of the transplanted bone serving as the proximal joint surface. This technique is discussed further under the the heading of arthroplasty.

Ununited fracture deformity of the phalanges was often corrected by excision of the area of nonunion, after which a block of bone was fitted into the defect and fixed with Kirschner wires. If the bony fragments were in contact and the nonunion not otherwise complicated, a bone graft taken from the ulna was fitted into a slot created in the bone. Bony union generally resulted when this technique was employed.

Defects in the bones of the forearm were corrected by the application of bone grafts from either the ilium or the tibia. Defects in the distal portion of the ulna were always less serious than those higher in the arm. If damage at the wrist was considerable, an arthrodesis (Fig. 191) was usually performed by means of an iliac bone graft applied across the articular surface. In many defects of the radius and ulna the defect was filled with bone from the ilium.

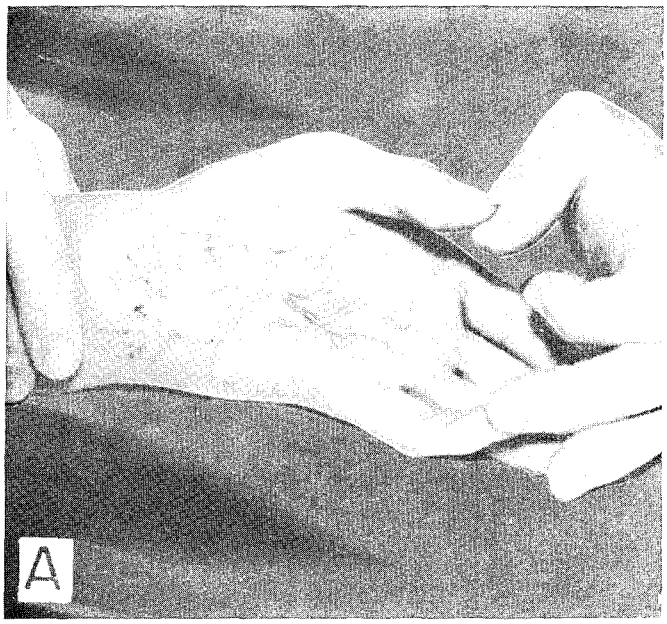



*Figure 189. A, and* **B** *(p. 372). Clinical and roentgenologic appearance of wound of left hand caused by explosion of a mine fuse held in the hand. A severe avulsion of the palm caused by small metallic particles which were in driven, resulted in dense keloid formation in the palm, adduction contracture and total loss of the opponens function of the thumb, loss of flexor tendon function of the little finger, and marked flexion contractures of the other fingers. There was total cutaneous paralysis over the ulnar distribution, and marked loss of cutaneous sensation in the index, middle, and ring fingers. C–E. Clinical and roentgenologic end results following reconstructive surgery. The first stage consisted of excision of the scar tissue, freeing of the scar about the cutaneous nerve supplied by the median nerve, and placing of an abdominal flap. One month later the multiple foreign bodies obstructing the flexor function to the fingers were excised. The others were left in situ. Later the flexor tendons to the ring finger were freed from scar tissue and the sublimis tendon to the finger excised. The 1½-inch defect in the cutaneous slip of the ulnar nerve was filled with a nerve graft taken from the lower extremity. The flexor profundus tendon of the little finger was sutured to the radial side of the profundus tendon of the ring finger. Still later a bone-graft-type of opponens operation was performed in which the first and second metacarpals were ankylosed together with a bone graft to hold the thumb in a position of opposition. When the patient was separated from service he had complete return of sensation to the thumb and all the fingers. He could flex the fingers, grasp objects, oppose the thumb, and could perform practically any duties required by the hand except those which necessitated motion of the proximal joint of the thumb.*

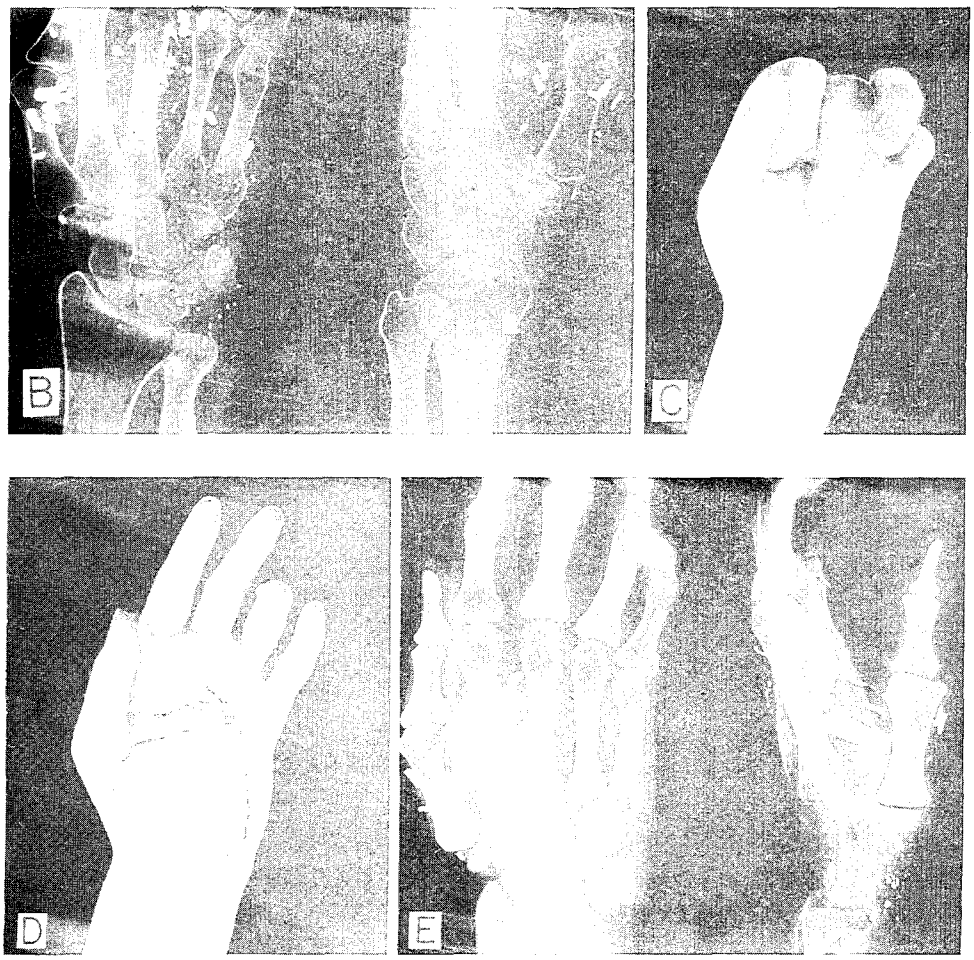



*Figure 189*—Continued.

A single Steinmann pin was used for the entire fixation; it extended through the marrow cavity in the bone graft into the distal fragment. In arthrodeses of the wrist a pin was frequently inserted by the same technique. A small incision was made into the palm of the hand, the nerves and tendons were retracted, and the pin threaded through the wrist into the marrow cavity of the radius. This method proved entirely satisfactory and greatly simplified the grafting of atrophic bone.

*Arthroplasty.* Arthoplasties of the metacarpophalangeal joints were performed on 29 occasions, the type of procedure being determined by the nature and extent of the injury. Arthroplasty in which the fascia is used

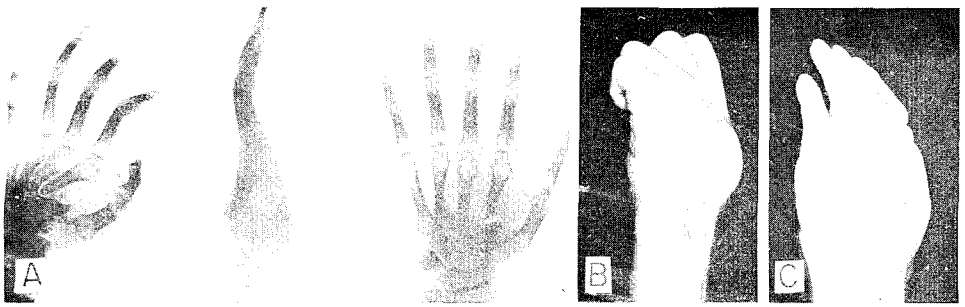



*Figure 190. A. Preoperative roentgenograms of left hand following injury by shell fragments, showing severe compound comminuted fractures of index and middle metacarpals with dorsal dislocation of the index metacarpal at the base and nonunion of the proximal end of the middle metacarpal. The extensor tendons were adherent to the bony structures and the extensive dorsal scar tissue. B and C. End results following surgery. After total excision of the scar an abdominal flap was applied to the dorsum of the hand. Two months later open reduction of the base of the metacarpal and excision of the area of nonunion of the third metacarpal were undertaken. Capsulotomies were performed on the metacarpophalangeal joints of the index and middle fingers, and the extensor tendons freed. A bone graft was placed at the base of the third metacarpal; fixation was accomplished with Kirschner wires. When the patient was discharged he had flexion to 70 degrees at the metacarpophalangeal joint with full flexion of the two distal joints of all the fingers. Function was excellent and he was able to carry out all of his previous activities.*

to form the joint was most often employed (Fig. 192). The wedge-type which consists of shortening the metacarpal bone was frequently used. Whenever an extensor tendon graft was necessary, attempt was made to perform it at the same operation. Special attention was paid to suture of the intrinsic muscles and to their attachment on the proximal phalanx to give lateral stability to the joint. It was the impression of the hand surgeons that lateral stability which prevents joint dislocation is nearly as important in repair of hand injuries as is the restoration of flexion and extension.

Surgeons at the Valley Forge General Hospital believed that ankylosis of the proximal interphalangeal joint was usually preferable to arthroplasty, which was performed on only 6 occasions. The major problem was to maintain flexor and extensor tendon function and lateral stability to the distal joints.

In a number of instances in which the articular surface of the metacarpal was severely damaged, with associated damage to the shaft, the fifth metatarsal bone was transplated to fill in the defect. The articular surface of the metatarsal then acted as the proximal articular surface of the metacarpophalangeal joint. By this procedure it was possible to restore 90 degrees of flexion

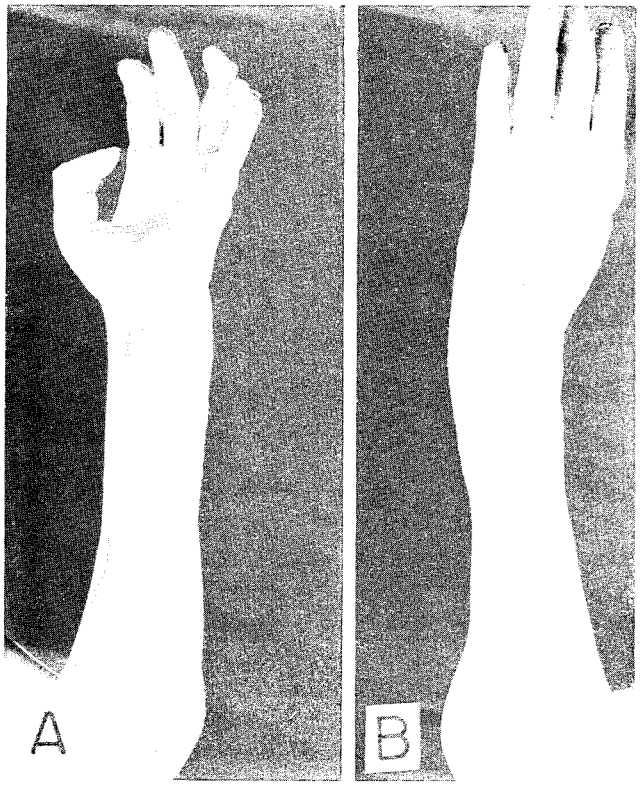



*Figure 191. Wound of left forearm which blew off flexor muscles and resulted in severe compound comminuted fractures of radius and ulna, with total ulnar nerve paralysis. When the patient was examined only five muscles of the forearm and hand were still functioning: The extensors of the finger and thumb, the flexor of the thumb, and the extensor carpi radialis longus and brevis. All other muscle bellies had been destroyed. Radial deviation of the wrist was present as a result of contracture and ulnar nerve paralysis, but the patient was still able to put the thumb in the position of opposition. A and B. Views of injured extremity following application of abdominal flap. C and D. Roentgenograms showing bone injury. E and F. End result. It was decided that the best procedure in this case would be to apply a large plastic flap after excision of the cicatricial area, to arthrodese the wrist, and later to transplant the extensor carpi radialis longus to the sublimis tendons of the fingers and the extensor carpi brevis to the profundus of the fingers. It was not thought necessary to graft the 4-inch deformity of the ulna. The procedures were carried out in stages as planned. The result was a good functioning hand, with ability to flex the fingers at all the joints and to oppose any of the fingers. The greatest residual defect was the loss of intrinsic control. Arthrodesis of the wrist prevented a hyperextension deformity, which usually occurs in paralysis of the ulnar nerve. There was excellent flexion of the thumb.*

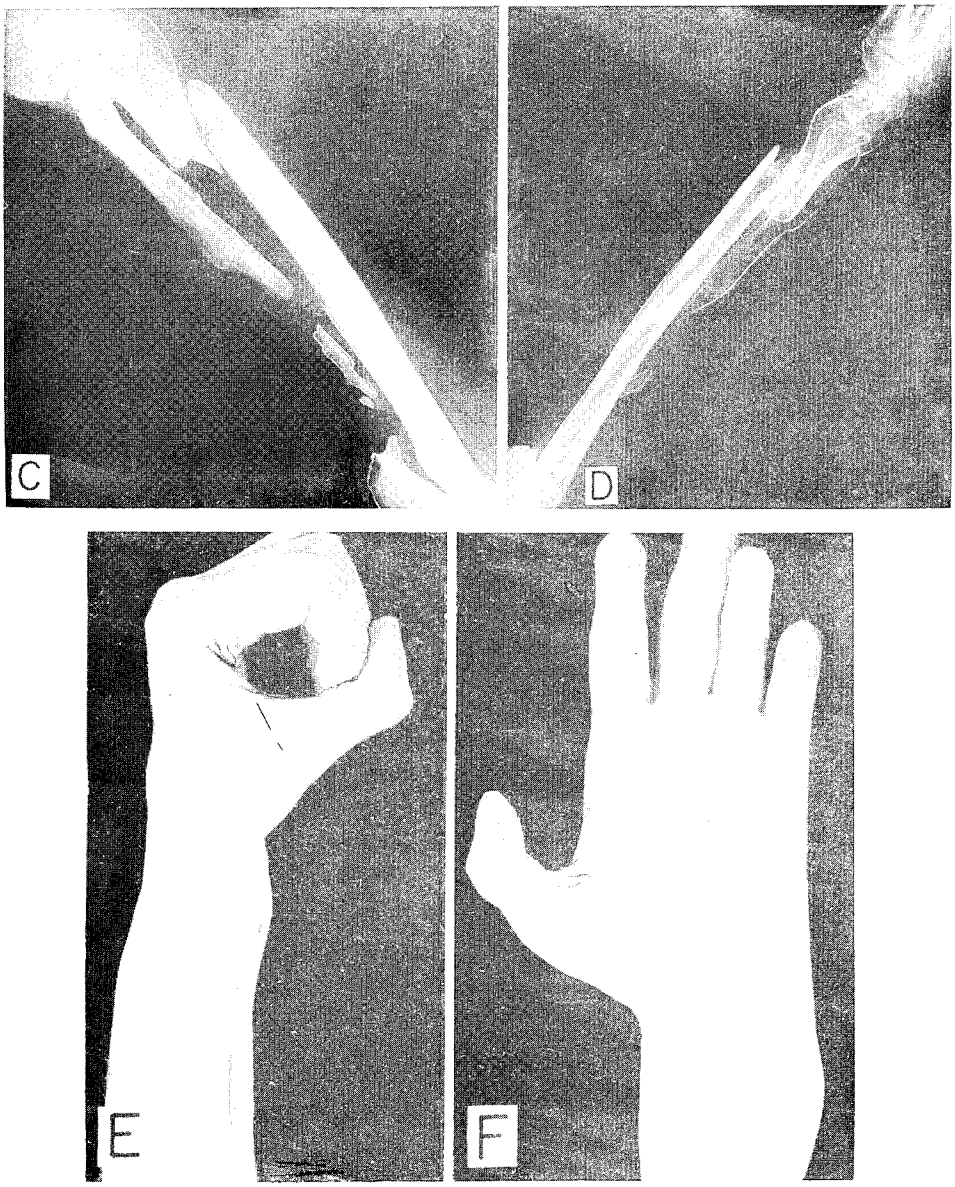



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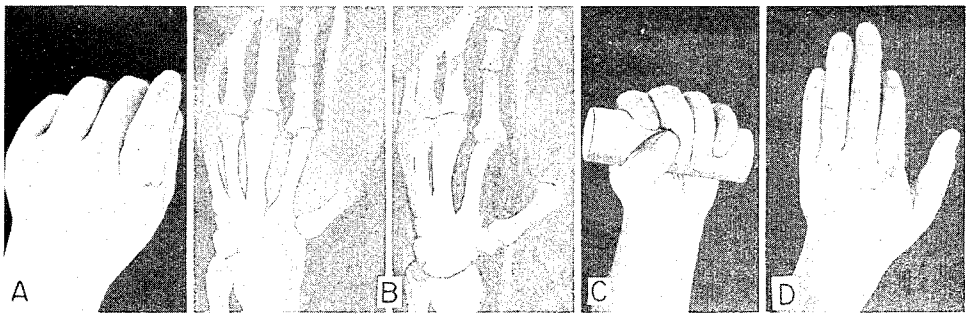



*Figure 192. A. Preoperative appearance of wound of left hand caused by shell fragments, resulting in a severe comminuted fracture of the distal end of the second metacarpal and of the tip of the proximal phalanx of the index finger. The metacarpophalangeal joint was totally destroyed and ankylosed. B–D. Roentgenologic and clinical end results following reconstructive surgery. The first procedure was a fascial type of arthroplasty on the metacarpophalangeal joint of the index finger; loss of bony substance had resulted in considerable shortening. The extensor tendon was sutured to the proximal end of the proximal phalanx and continuity of the intrinsic muscles was re-established to give lateral stability. The result was an excellently functioning hand with 80 degrees of motion at the metacarpophalangeal joint, and flexion adequate for good function. Reattachment of the intrinsic muscles restored the ability to abduct and adduct the hand.*

and give the patient a useful joint. In many cases it was necessary to carry out a sublimis transplant in order to restore flexion in the metacarpophalangeal joint and to restore extension to the two distal joints of the finger.

When a tendon graft had not been necessary, early motion was begun soon after operation. If a tendon had been grafted, a period of 21 days was allowed to elapse before motion was instituted. It was not found necessary to apply traction when an arthroplasty had been performed.

## Tendon Injuries

Since motor function is necessary for flexion and extension of the fingers and thumb, restoration of motor function to a finger is almost as essential to the function of the hand as the restoration of sensation. That function had in many cases been lost because of destruction of the continuity of the tendons (Figs. 193–198).

*Tendon Suture.* Motor function was restored by the suture of tendons if this was in any way possible. It was not always necessary to suture tendons to their original muscles; it was frequently advisable to suture a tendon to a muscle which had maintained its function in spite of injury, particularly when the flexors and extensors in the forearm were involved. The long flexor of the thumb, when the muscle belly had been destroyed, could be attached to a sublimis

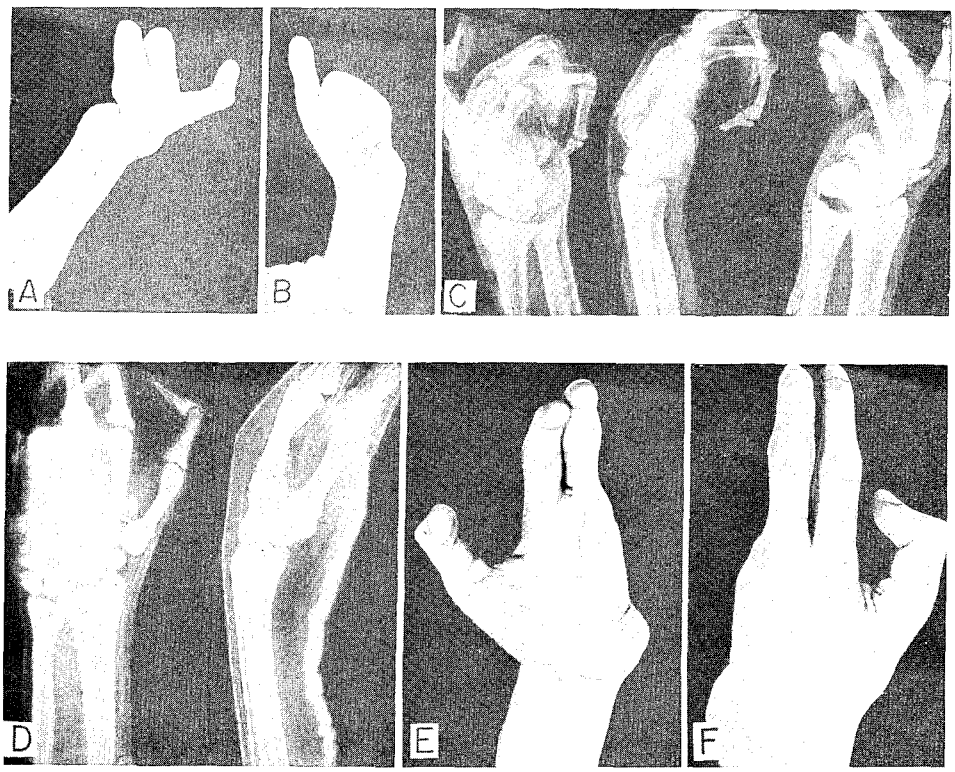



*Figure 193. A–C. Injury to left hand from explosion of land mine, with complete amputation of the ring and little fingers and the corresponding metacarpal bones; severe fractures of the index and middle metacarpals with upward displacement of the distal fragments, and marked shortening and nonunion; a severe fixed flexion contracture of both of the remaining fingers with serious injury to the flexor tendons of the middle finger. Sensation was present in the remaining digits. D–F. Roentgenologic and clinical end results following surgery. The first step of reconstruction was excision of the scar, filling in of the defect with a remote flap, and reduction and fixation of the second and third metacarpal bones in a normal position, then the fixed flexion contracture of the two remaining fingers was released. The flexor tendons to the middle finger were completely excised and skeletal traction applied to this finger for 6 weeks before full extension was obtained. The flexion contracture of the index finger was released by freeing the sublimis tendon at its distal attachment, extending the finger, and suturing it with sufficient lengthening into the previously divided profundus to allow extension. Three months later a tendon graft was placed in the middle finger. The result was about 40 degrees of flexion of the two distal joints and full flexion at the metacarpophalangeal joint. A flexion deformity of the distal joint of the thumb had existed for many years before the present injury but was not considered a problem since the patient had learned to use his hand well with that deformity present.*

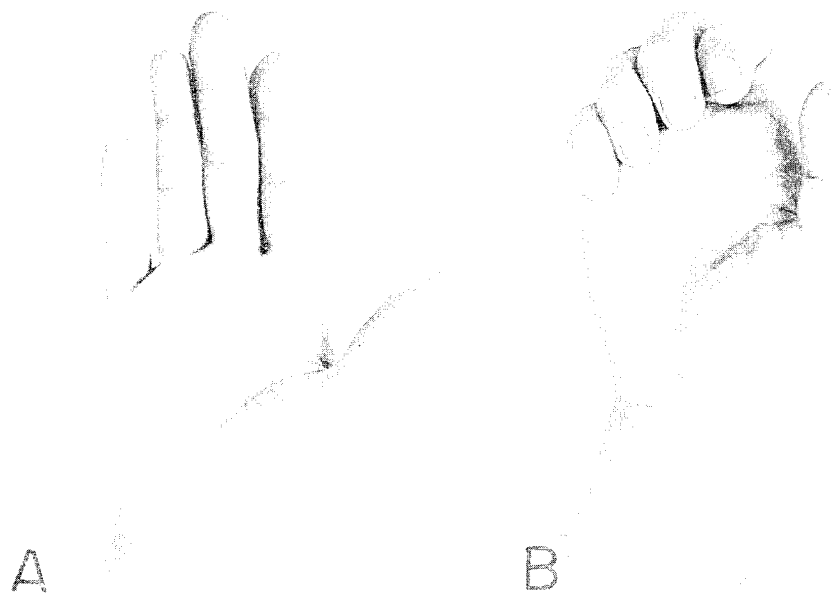



*Figure 194. A and B. Injury of right hand resulting from cut on a C–ration can with severance of the cutaneous nerve to the radial side of the thumb and injury to the flexor tendon. The tendon was sutured immediately but when the patient was admitted there was no flexor tendon function present. A flexor tendon graft to the thumb was carried out immediately. Six-and-a-half months later the cutaneous nerve was explored and sutured. There was almost complete return of flexor tendon function to the thumb together with return of sensation to its ulnar aspect.*

tendon and normal range of motion restored. Often the palmaris longus was used to replace a muscle or tendon to a finger or the thumb. On numerous occasions the flexor tendons were lengthened by detaching the distal attachment of the sublimis, cutting the profundus tendon, accomplishing the desired length, then suturing the distal portion of the profundus into the sublimis.

It was never regarded a safe procedure to suture a tendon in an area which was the site of cicatricial changes, particularly in the palm, where a tendon sutured in scar tissue invariable became adherent. An injury of this sort was often managed by resecting the scar and later performing a tendon graft.

It was also found inadvisable to perform tendon suture between the middle crease of the finger and the distal crease of the palm. This is an area in which tendons notoriously become adherent because of the small size of the pulleys through which they must slide.

Very little trouble was experienced in suturing a flexor tendon in the distal half of the middle phalanx or in the base of the palm. When the suture line

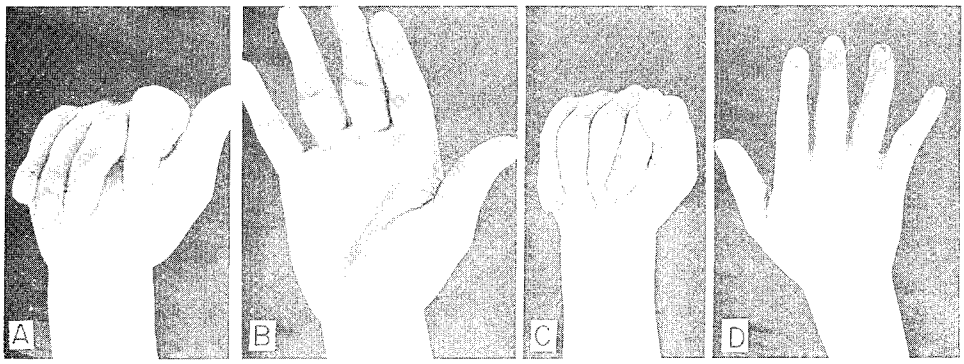



*Figure 195. A and B. Preoperative appearance of right hand following severe laceration of the flexor tendon of the middle, ring, and little fingers in the region of the middle joint, with no flexor tendon function to the two distal joints of these fingers. C and D. End results following surgery. Flexor tendon grafts were placed in the ring and middle fingers and the flexor tendon to the little finger sutured. The pulleys of the fingers were left intact. The sublimis tendon in each finger was used for motor power for the flexor tendons. The profundus tendon of the little finger was pulled downward and fixed to the middle phalanx; no attempt was made to restore function to the distal joint. The flexor tendon to the ring finger became adherent and it was necessary to perform medial and ulnar nerve blocks to tear loose the adhesions and restore function.*

lay in the base of the palm a lumbrical muscle was wrapped around it to prevent it from adhering to surrounding tissue. Restoration of flexor tendon function beneath a palmar flap was rather difficult, probably because of the extensive scarring which had originally required the placing of the flap.

Special problems arose when tendons had to be sutured on the dorsum. Extensive scarring usually required the placing of an abdominal flap before deep operations were carried out. Transfer or suture of tendons was deferred to a later stage and was not performed at the time of the flap operation. An attempt was always made to maintain individual action in the index finger. When the dorsum of the hand was severely damaged, the extensor indicis proprius tendon was usually used to control the index finger, the communis muscle to control the ring and middle fingers, and the digiti quinti to control the little finger.

Repair of tendons in the fingers presented more serious problems than their repair in the body of the hand. The extensor tendon was often severely damaged and adherent to both bone and scar tissue. This tendon is normally attached to the base of the proximal phalanx and when this attachment was destroyed a flexion deformity occurred at the metacarpophalangeal joint. Such a deformity, particularly frequent in burns, was always annoying because it meant the loss of extensor control of the proximal phalanx. The damage was

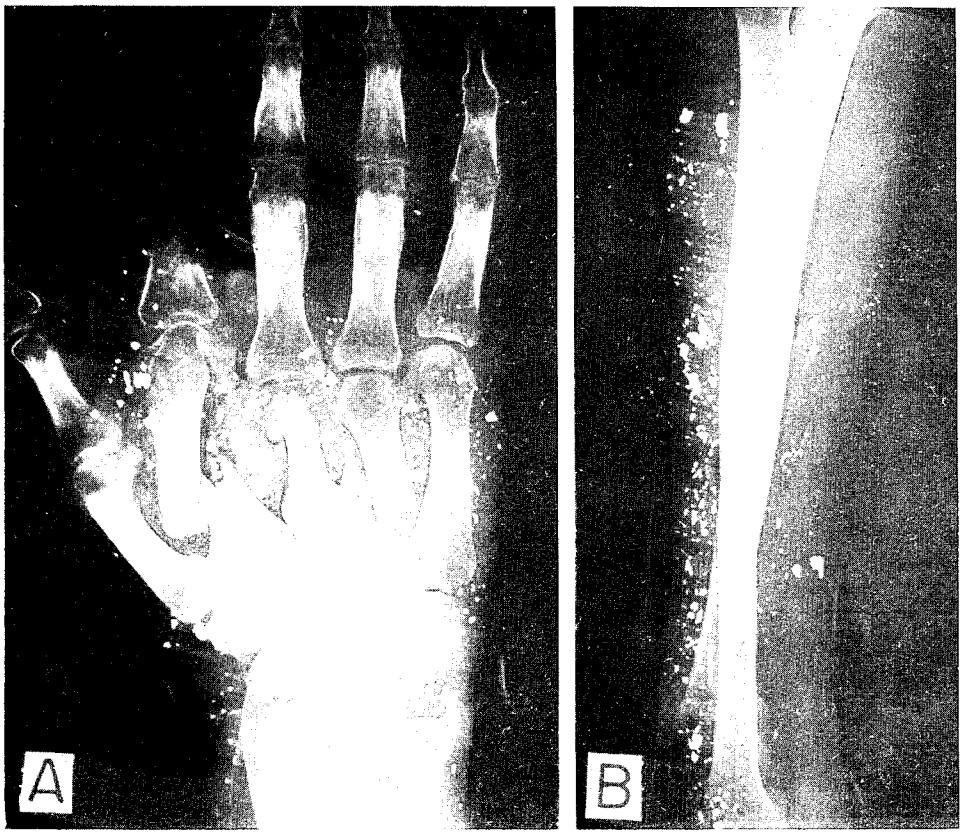



*Figure 196. A and B. Roentgenograms of right hand and forearm following injury from explosion of dynamite. Severe loss of soft tissue from the metacarpophalangeal joint on the dorsum of the hand up to the middle of the forearm; total loss of the extensor tendons, bones of the metacarpals and the distal end of radius exposed; a traumatic amputation of the index finger and very severe compound comminuted fractures of the second, third, fourth, and fifth metacarpals. Patient was unable to flex or extend the fingers at the metacarpophalangeal joints. C–F. Roentgenologic and clinical end results following reconstructive surgery. After excision of the scar tissue on the dorsum, the defect was completely covered by an abdominal flap about 10 inches in length. To free the thumb, held outward and dorsalward by a great deal of scar tissue, and to release the scar, the index metacarpal was resected back to the base. The middle metacarpal head, which was very severely damaged, was replaced by transplanting the head and part of the shaft of the second metacarpal. Extensor tendon function was re-established by means of an extensor tendon graft about 11 inches long which was secured from the foot; the long extensors of the toes were used as grafts to re-establish extensor tendon function to the middle, ring, and little fingers. These procedures occupied a period of about 8 months. At the end of this time the patient had well over 90 degrees of motion at the metacarpophalangeal joints. The joint formed by transplantation of the metacarpal bone had 100-degree motion with-*

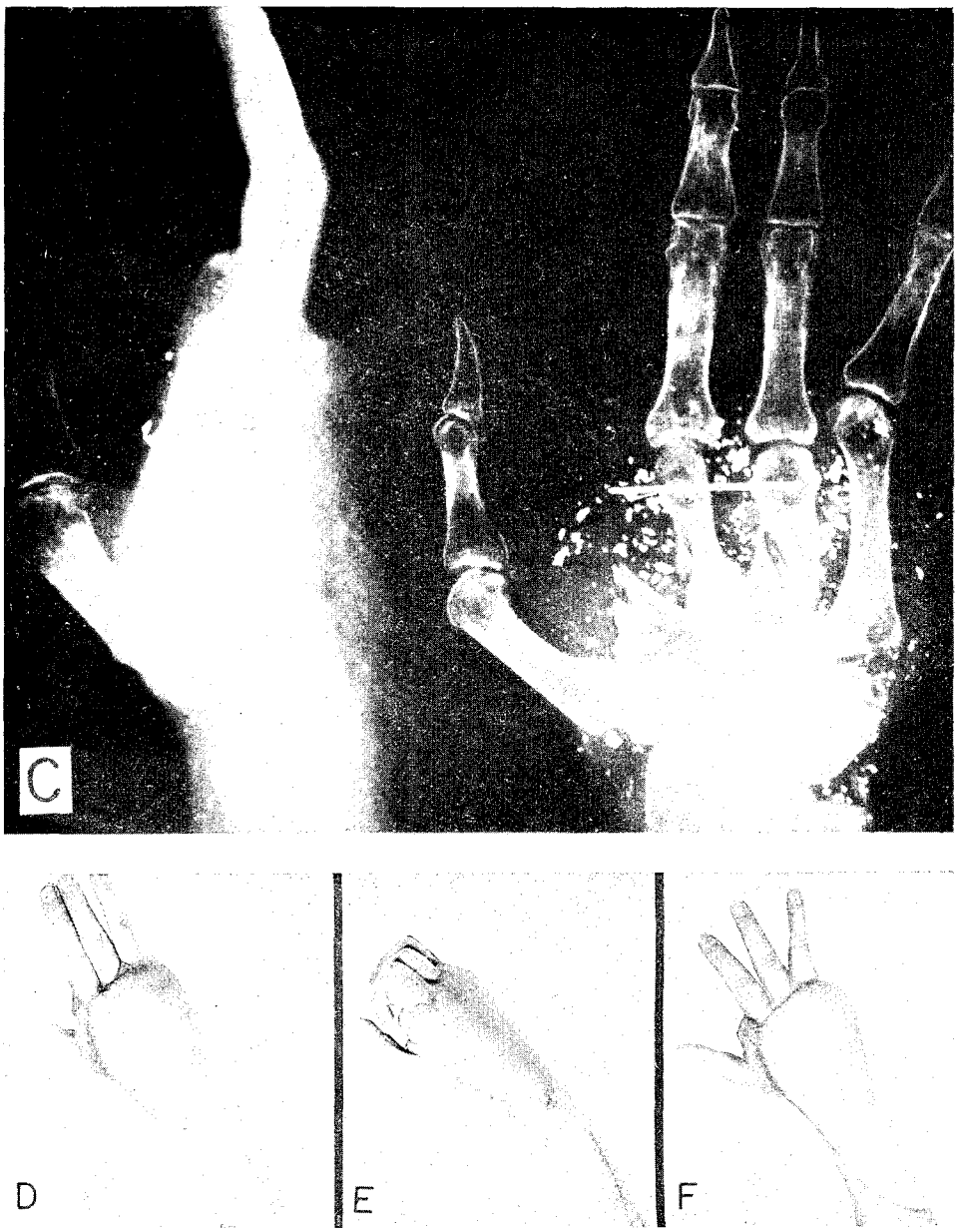



*Figure 196*—Continued.

*out discomfort. The patient was able to extend and flex his fingers, although there was some limitation of full flexion of the metacarpophalangeal joint as the result of severe damage to the intrinsic muscles. He was left with an excellently functioning hand which was particularly useful because this patient had sustained total loss of vision in the same accident which injured his hand.*

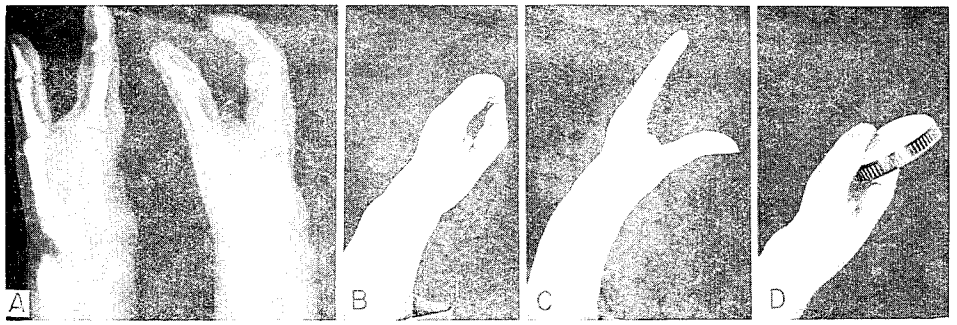



*Figure 197. A. Preoperative roentgenogram following shell fragment injury of left hand showing traumatic amputation of third, fourth, and fifth fingers and fracture of the second metacarpal bone with nonunion. The extensor tendon of the index finger was also lost. A wound of the forearm resulted in severe damage to the ulnar nerve and the muscle belly of the flexor of the thumb, compound comminuted fractures of both radius and ulna, and loss of substance of the carpal bone. The wound of the hand had been closed by a split skin graft before the patient was seen. B–D. End results of surgery. The first operation consisted of excision of the area of nonunion of the second metacarpal and tendolysis of the flexors of the index finger and thumb. The fractured metacarpals healed satisfactorily, but the flexor tendon of the thumb readhered because of severe scarring of the muscle belly. Transplantation of the sublimis tendon of the missing fingers, to act as a flexor of the thumb, was then undertaken, and the extensor indicis proprius tendon was freed from its distal attachment and placed at the radial side of the proximal phalanx of the index finger. When the patient was discharged he had full range of flexion of the thumb and ability to stabilize the index finger against it. Full flexion and extension of the index finger was possible because the lumbrical muscle which supplied the median nerve was still intact. He was able to tie his shoes, button his shirt, and pick up small articles.*

corrected by splitting the extensor tendon and fixing it to the base of the proximal phalanx in its normal position.

Suture of the extensor tendons in the distal part of the fingers was discouraging because of lack of soft tissue. A flap was frequently necessary before continuity of the tendon could be re-established.

*Tendon Grafts.* When continuity of tendons could not be re-established by suture, the defect was repaired by tendon grafts. Tendon grafts were performed on 195 individual patients at the Valley Forge General Hospital. On many occasions as many as 3 or 4 were carried out at the same operation. The number of separate grafts was well over 400.

A tendon graft practically always functioned without difficulty if it was placed in a bed in which the circulation was not constricted by scar tissue. When scarring was extensive a transplant was employed instead of a graft. A tendon graft established itself and became available for motor function within the same period of time as did a tendon sutured end to end.

Grafts were not satisfactory if the tendon used was one of the larger ones; the center could be expected to become necrotic because tendons are nourished by tissue fluids, which must reach all portions. Smaller tendons had no difficulty in surviving and did not become adherent to surrounding tissues.

When extensor tendons on the dorsum of the hand had to be replaced it was found best not to use a separate graft for each finger. Frequently only 2 grafts were used for the 4 fingers; never more than 3. The distribution was as already described (p. 379). Because of their tendency to adhere to it tendons were never sutured beneath a line of incision.

In 46 instances flexor tendons of the fingers were replaced. The technique employed was to suture proximally with silk at a level at which there was no scarring; this was either in the base of the palm or above the wrist. Soft tissue injury always determined at what level the suture was carried out. The grafts were fixed distally with Bunnell pullout wires which attached them to the distal end of the tendon, or if tendon was not present the suture was elevated to the periosteum or directly inserted into the bone.

Attempt was made to repair at one operation all fingers with damaged tendons, so that it would not be necessary to splint the hand more than once. Nerves were frequently sutured at the same time. This was true also of all the work necessary in the palm, in order to decrease the amount of surgical scarring.

Motion was not permitted until at least 21 days after operation. Then the splint was removed and moderate active and passive motion begun. At the end of 4 weeks full muscle function was encouraged; further, to promote tendon function the patient was started on occupational therapy. On a few occasions a median and ulnar nerve block was carried out so that he could manipulate his fingers actively. By this method it was possible to free adhesions and increase the restoration of function.

Flexor tendon grafts to the thumb proved particularly satisfactory. The graft was sutured at the level of the wrist and was usually fixed distally with the pullout wire technique described by Bunnell.

Except in cases in which the laceration was distal to the attachment of the sublimis tendon in the fingers it was common practice to resect the sublimis and use a single graft. In an injury of the latter type the graft was applied to the profundus, leaving the sublimis intact.

When tendon grafting was needed in the forearm to fill in defects in the tendons in the wrist, a single tendon was seldom used for each finger. The long flexor of the thumb was always repaired with a separate graft but otherwise a single tendon was usually used for two fingers. Tendon grafting in the forearm was frequently combined with suture of the median nerve.

The release of adhesions in the hand and forearm was an important part of the restoration of function. Frequently, tendolysis, capsulotomy of the joints, and transplantation of fascia were required to prevent readherence.

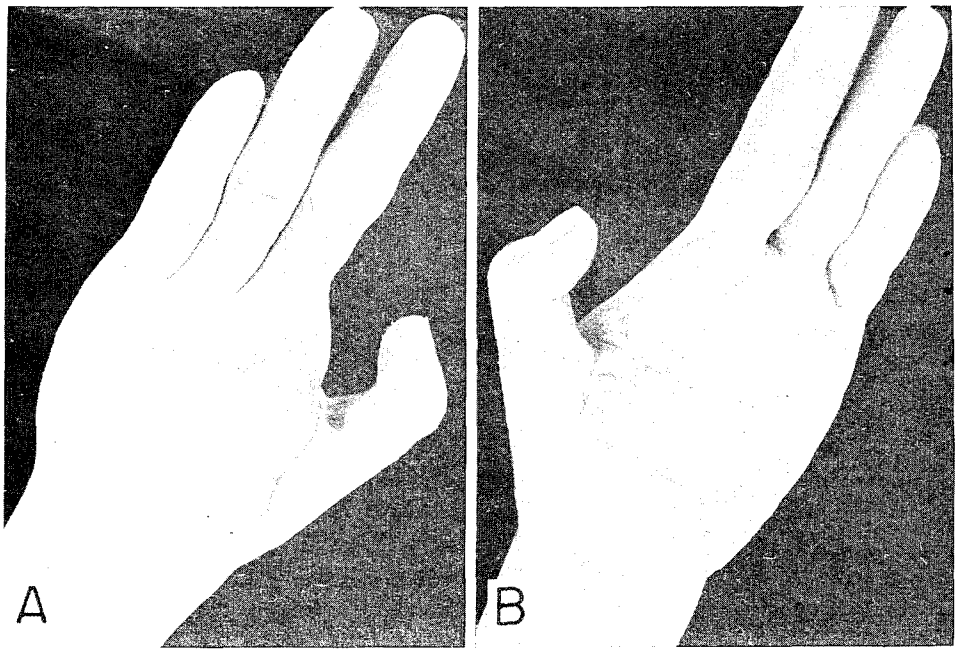



*Figure 198. A–C. Clinical and roentgenologic appearance of left hand following injury from the explosion of a 20 mm. shell. The index finger was torn away just proximal to the head of the metacarpal bone. There was a severe injury to the distal end of the thumb, with compound fractures of both phalanges, and loss of flexor tendon function to the distal joint which was ankylosed in 90 degrees of flexion. A contracting scar held the thumb in the position of adduction so that it could not oppose the remaining fingers. D and E. End results of surgery. The contracting scar holding the thumb in adduction was excised on the plastic service, and the defect filled by an abdominal flap. The patient was still unable to oppose the thumb toward the hand. The opponens muscle was still functioning but the injury had apparently totally destroyed the adductors of the thumb; it was necessary to replace them by a transplant. When this was done, the distal joint of the thumb was resected and fixed in full extension. The sublimis tendon of the missing finger was threaded through a pulley made in the palm, and the distal portion of the tendon carried out and sutured to the ulnar side near the head of the first metacarpal. The patient was then able to adduct the thumb and hold it tightly against the middle finger. He also had full range of motion in abduction. Although he had no flexor function in the distal joint of the thumb, it was ankylosed in the position of function. The end result was an excellently functioning hand with which he could perform practically any duties.*

Tendons were often found attached to subcutaneous tissue as well as to fascia and bony structure. When scarring was present or bones exposed, a piece of fascia was taken from the forearm or thigh, the slippery side placed next to the tendon and sutured between the tendon and the scar or bone. This

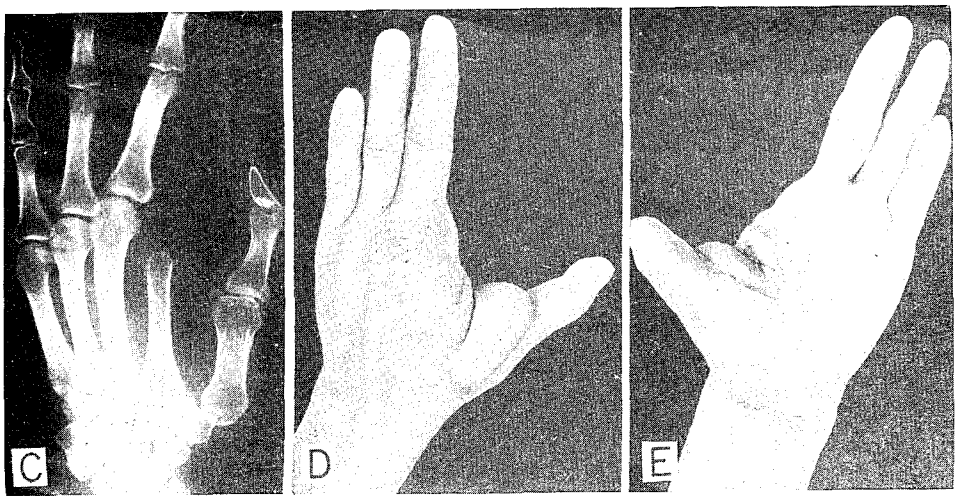



*Figure 198*—Continued.

procedure, which could be carried out concurrently with the tendon grafting, was found helpful in permitting the tendon to function when the proper time arrived.

Capsulotomy of the metacarpophalangeal joint (Figs. 187, 190, and 199) was useful, particularly in patients who presented malunion of fractures of the metacarpals in which the head had dropped toward the palm, as well as in paralysis of intrinsic muscles of such a character that the metacarpophalangeal joint was pulled into extension. It was found almost impossible to correct this deformity without cutting the ligaments in the metacarpophalangeal joint and putting the joint into a position of flexion by manual manipulation.

If the area of scarring was minimal tendolysis of the flexor tendons was usually sufficient. If adhesions extended for a considerable distance, the possibility of restoring tendon function was always extremely doubtful. When tendolysis was performed on the flexor tendon the sublimis was excised and a single tendon left to mobilize.

If wounds involving the intrinsic control of the fingers were associated with loss of extensors of the two distal joints, it was often found a good procedure to free one of the proprius tendons at its distal attachment and attach it with a tendon graft to the proximal end of the middle phalanx. Extension of the distal joints was promoted by this procedure, which was also useful when the extensor tendon over the proximal interphalangeal joint was disrupted. In this type of injury the extensor tendons to the distal joint were still intact and it was necessary only to attach the tendon to the proximal end of the proximal phalanx.

When intrinsic control was lost, the extensor sleeve could be freed from the volar interosseous or lumbrical muscle, brought down dorsally, and sutured to

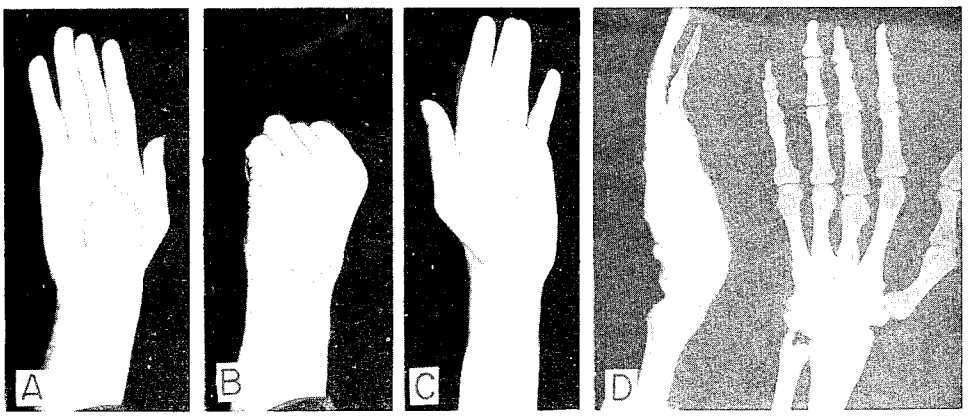



*Figure 199. Injury of dorsum of left hand by shell fragment, with loss of soft tissue and fracture of base of third and fourth metacarpals, with moderate shortening. There was a hyperextension deformity of the metacarpophalangeal joint of the middle and index fingers. As a result of soft tissue contracture on the dorsum of the hand there was also an adduction deformity of the thumb. A–D. Clinical and roentgenologic end results. Surgery consisted of excision of the scar tissue; the application of an abdominal flap to the dorsum of the hand, capsulotomy of the involved metacarpophalangeal joints, and suturing of the extensor tendons. After operation flexion of the metacarpophalangeal joints was possible and the patient had a strong grip and good extension of the fingers.*

the proprius. This procedure also furnished excellent extension to the distal two joints of the fingers. Extensor tendon grafts to promote extension of the distal joint were, on the whole, unsatisfactory. There is not sufficient soft tissue in this area for a tendon to slide beneath, and the grafted tendon almost inevitably became adherent.

Grafting in injuries of the arm seldom presented difficulties. In most such injuries a finger was likely to be missing and its tendons could be used. When the sublimis had to be excised, it could be used as a graft for flexor tendons. When grafts could not be secured from within the hand, the most readily available sources were the long extensors of the toes, from which grafts as long as 8 to 12 inches could be secured.

*Muscle Transplants and Tranfers.* Muscle transplantation operations were most frequently employed in radial nerve paralysis. The flexor carpi ulnaris and radialis were freed from their distal attachments and rerouted around the arm, where they were sutured into the extensors of the fingers and the extensors and abductor of the thumb.

Various modifications of this classic procedure were employed. If the patient had a strong palmaris longus, it was used on occasion as an abductor of the thumb and the other tendons used only on the extensors. If the palmaris

longus was a smaller muscle, it was frequently attached to serve as the long extensor of the thumb so that the thumb would have individual action. On a number of occasions the sublimis of the ring finger was transferred to act as a long flexor for the thumb, as was the palmaris longus. The extensor radialis longus was frequently used as an abductor to stabilize the thumb.

The pronator teres was sometimes freed from its attachment and turned to act as a supinator of the forearm. A portion of the medial epicondyle with attached muscles was transplanted by the Steindler technique [2] to supply flexion of the elbow in patients with biceps and brachialis paralysis.

In ulnar nerve paralysis, or in severe injuries in which the abduction power of the index finger was lost, the extensor indicis proprius might be routed through a new channel and fixed to the radial side of the base of the proximal phalanx to act as abductor, according to the Bunnell technique. Excellent stabilization was provided by this method. A flexor sublimis was sometimes used in the same manner since this muscle is much stronger than the extensor indicis proprius. It was rerouted along the outer border of the thumb to the radial side of the proximal phalanx of the index finger. Procedures of this kind proved extremely valuable in stabilizing the index finger against the thumb and preventing ulnar deviation of the fingers.

The most extensive transplantations consisted of using sublimis tendons to replace paralyzed or destroyed intrinsic muscles. This procedure, devised by Bunnell, consists of freeing the tendons from their original attachments, rerouting them through the lumbrical canal, and reattaching them to the extensor sleeve so that they may act as flexors for the metacarpophalangeal joint and as extensors for the interphalangeal and distal joints. For a single finger, or for a part of the hand in which the intrinsic muscular control had been destroyed, the procedure was modified. It was extremely satisfactory in cases of paralysis in which there was no scarring in the palm and tissue was free for transplantation of tendons. When necessary, the entire intrinsic control of the finger could be restored by transfer of the sublimis in this manner. To supply adequate motor units, the sublimis was frequently split well up into the hand, half of the tendon was then placed on the ulnar and half on the radial side of the two adjacent fingers. It was extremely important that the tendons be placed on the same side of the fingers; otherwise abduction and adduction pull would have been lost.

In all tendon transfers an attempt was made to allow proper excursion for the new function the tendon was expected to perform. This rule could not be entirely adhered to, however, and often had to be modified.

*Opposition Operations.* Next to the restoration of sensation and motor function, the most important objective in reconstructive surgery was furnishing

[2] Steindler, Arthur: Orthopedic Operations. Springfield, Charles C Thomas, 1940, p. 129.

the patient with the ability to oppose the thumb to the fingers so that he could grasp objects between them. Tendon opposition operations were performed in 18 patients. The procedures utilized for this purpose depended upon the particular damage to the hand (Figs. 200–202).

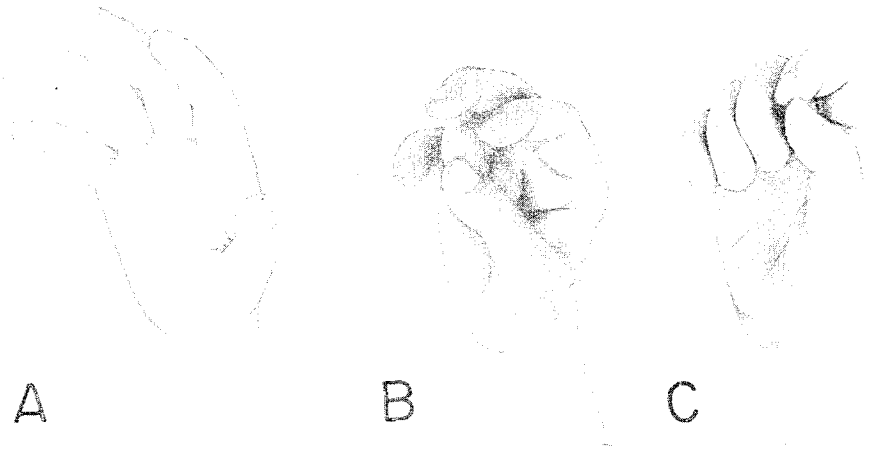



*Figure 200. A. Deformity of the hand from a bullet wound sustained some 8 years earlier, resulting in total inability to oppose the thumb to the fingers. B and C. Results of opponens operation. The flexor carpi ulnaris was used as the motor power and was turned back as a pulley for the tendon to pull through.*

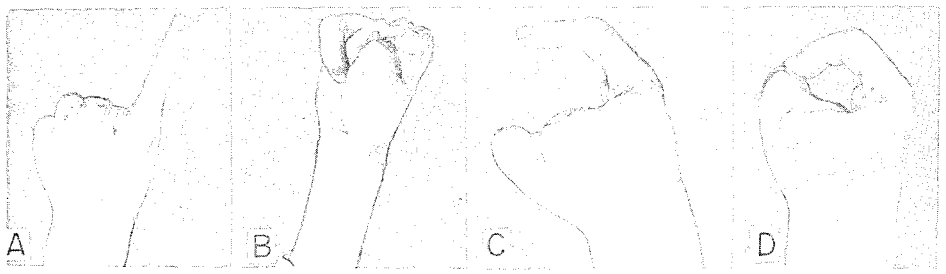



*Figure 201. A and B. Traumatic amputation of index, middle, and ring fingers of right hand and of thumb at metacarpophalangeal joint. The stump of the thumb remained mobile and excellent flexion function was preserved in the fifth metacarpal. The second, third, and fourth metacarpals were greatly scarred on the distal ends and the flexor tendons were adherent to them. C and D. Results of surgery. Resection of portions of the second, third, and fourth metacarpals allowed the hand to close, rotation osteotomy of the fifth metacarpal allowed the little finger to oppose the thumb. These operations resulted in a strong lobster-claw-type of hand which the patient was able to use for many purposes. A hand of this kind is obviously more useful than one in which, as originally, the only possible function was contact of the hypothenar eminence with the little finger.*

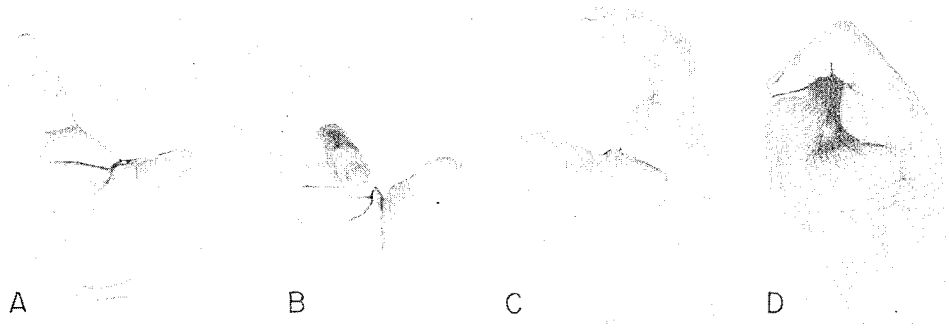



*Figure 202. A and B. Preoperative appearance of right hand following severe wound from shell fragment resulting in total amputation of the middle, index, and ring fingers and of the distal third of the corresponding metacarpals. The thumb was amputated at the metacarpophalangeal joint. There was also malunion of a fracture near the base of the fifth metacarpal. The patient had full flexor motion of the little finger but was unable to utilize his hand beyond opposing the little finger against the palm. C and D. Results after surgery. After excision of scar tissue, the malunited fracture at the base of the fifth metacarpal was resected, the shaft of the fourth metacarpal removed, and the fifth metacarpal transferred to the base of the fourth. The fifth metacarpal and the little finger were then rotated so that they could oppose the thumb without exertion, and were fixed in this position with Kirschner wires. Six weeks later the amount of rotating was increased as the degree of opposition had not proved sufficient. The end results in this case were good, the patient being able to use his hand for any light function. It was particularly important that he have a functioning hand as he had lost most of his vision at the same time he sustained his hand injury.*

If the defect was purely motor nerve paralysis of the opponens muscle, the opposition operation described by Bunnell gave extremely satisfactory results. The basis of this operation is the attachment of the motor power (supplied by the tendons) to the ulnar side of the base of the proximal phalanx of the thumb with the subcutaneous pull in the direction of the pisiform bone.

Numerous tendons are available to supply motor power, and the choice of the tendon to be used for this purpose depended upon the condition of the hand. If a finger or fingers had been amputated, the sublimis tendons therefrom were used to supply motor power to the opponens muscle; the flexor carpi ulnaris was frequently used, a pulley being turned back to keep the tendons pulling in the direction of the pisiform bone; the palmaris longus was excellent for the purpose if the muscle was well developed. In one patient it was necessary to use an extensor carpi radialis because of the general weakness of the flexors of the fingers and wrist. From the standpoint of opponens function the end results were excellent.

The adductor muscle was occasionally stripped from the first metacarpal to allow it to come out in a position of opposition. A few times it was neces-

sary to perform an osteotomy near the base of the first metacarpal and rotate the thumb into position because the thumb had been held in adduction over a long period and a contracture of the articular ligaments prevented return to its normal functional position.

If scarring in the palm was extensive, it was necessary to resort to a bony type of opponens fixation. A bone graft was placed between the first and second metacarpals to hold the thumb in the opponens position until bony union had occurred. In a number of patients in which only the index finger and thumb remained, no tendon operation was necessary. Instead, an osteotomy was performed on the metacarpal of either thumb or index finger and the metacarpal rotated into a position in which the digits opposed each other.

This type of operation is of no value unless the patient is able to flex the fingers so that they will grasp against the thumb. When this power was lacking, therefore, the first step was accomplishment of tendon and nerve repairs necessary to restore useful fingers.

## Restoration of the Thumb

Frequently it was necessary to reconstruct a thumb (Fig. 203) or to realine the stump of a thumb into a position in which the fingers could oppose it. In a number of instances of this kind a tube pedicle was first constructed; later a bone graft (usually from the rib) was inserted to give the tube stability. Bone from a rib was preferable for this purpose, as it could be bent to the correct position and union occurred in a much shorter period. In the restoration of a thumb the skin of the hand was preserved at the point of contact with the fingers to maintain tactile sensation, and tissue from distal areas was used to fill in the defects since maintenance of sensation of the opposing surface of the thumb was extremely important.

When the index and middle fingers did not make contact with the stump of the thumb, an osteotomy was done at the base of the first metacarpal which was put in malalinement so that the stump would be held toward the palm in a position to make contact with the fingers. This was particularly important when only the little finger remained on the hand and contact with the stump of the thumb was needed. The resulting so-called lobster claw was always extremely useful to the individual because a certain amount of function was thus preserved.

## Transposition of Digits

Transposition of fingers (Figs. 204 and 205) proved to be a highly satisfactory method of restoring function to hands damaged by shell fragments. It was usually reserved for cases in which a missile had passed through the hand from the dorsal to the volar area, or vice versa, injuring the metacarpal bone, and the nerve, tendon, and blood supply to a finger. When the third

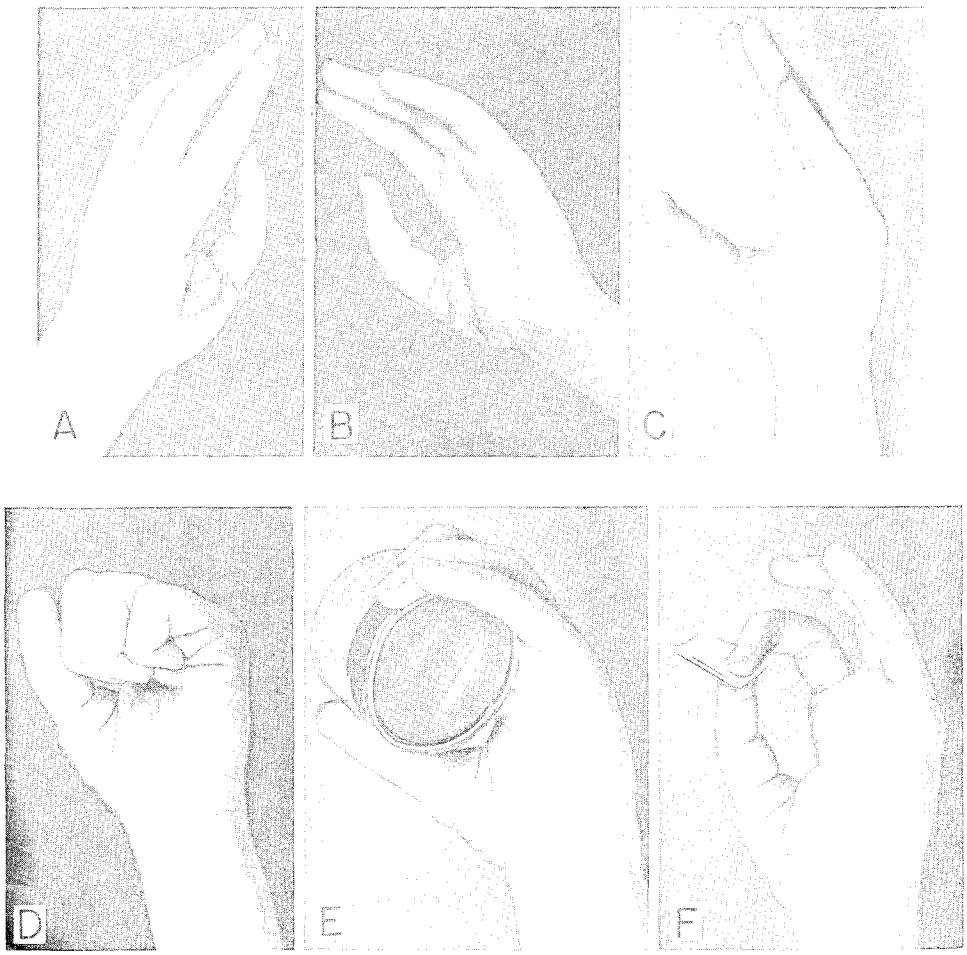



*Figure 203. Total loss of thumb, fracture of second metacarpal, from shell fragment injury. Reconstruction of thumb. A. Dorsal view of hand after application of flap and first-stage transposition of index finger. B. Palmar view. C. View of hand after completion of staged surgery, showing abduction of thumb. The tip of the index finger has been amputated to provide for a two-joint digit. D–F. Functional results. The patient has no difficulty making a fist or holding large and small objects.*

metacarpal was so badly damaged that loss of sensation, cicatricial contracture, and tendon damage made restoration of function impossible, the finger was amputated and metacarpal bone resected down to the base, which was left in situ. The second metacarpal was then osteotomized near the base and the index finger transplanted to the base of the third metacarpal. Thus the hand was narrowed and the defect eliminated. The web was formed by closure of the

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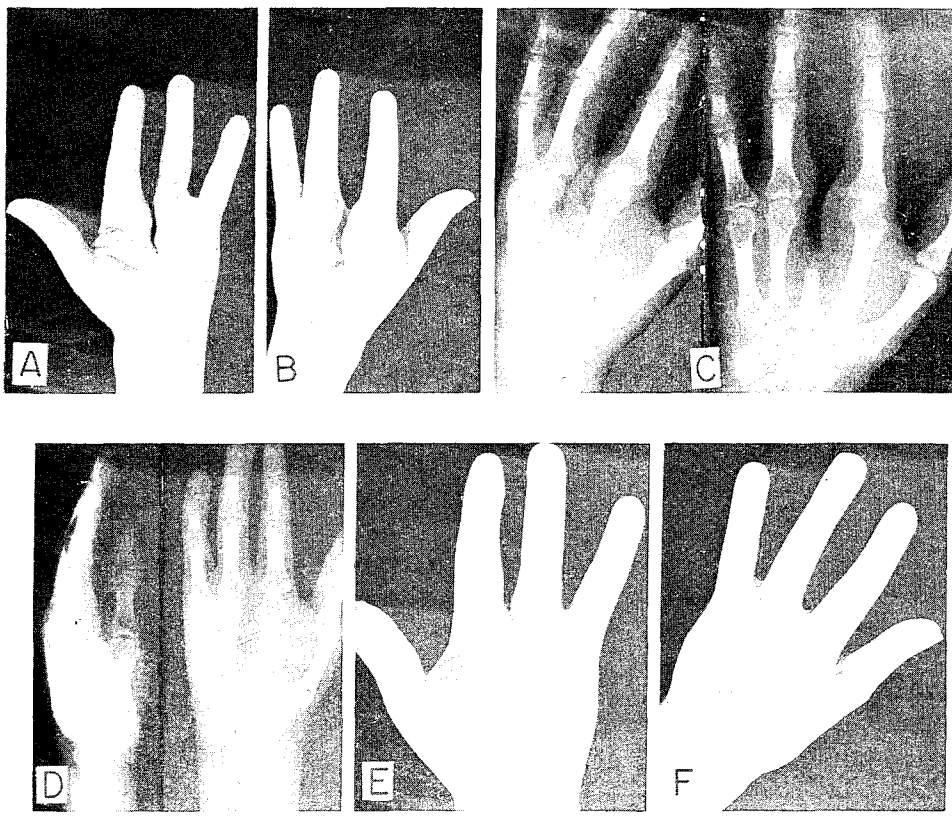



*Figure 204. A–C. Clinical and roentgenologic appearance of wound of left hand caused by accidental discharge of the soldier's own rifle. The bullet passed through the hand, tearing out the middle finger and the distal two-thirds of the third metacarpal bone and leaving a large defect in the palm. To this a split skin graft had been applied. The patient had a painful neuroma in the palm, also great stiffness of the fingers with inability to flex the joints more than a few degrees. D–F. Roentgenologic and clinical results following surgery. The scar in the crease between the index and ring fingers was excised and the neuroma dissected well back into the carpal canal. The index finger was transposed to the base of the third metacarpal so that the hand was narrowed and the soft tissues could be brought together without the persistence of a cleft. Later, tendolysis was employed to free the tendons and permit flexion of the fingers. When the patient was separated from service the cleft was completely eliminated and function was excellent.*

wound. It was frequently possible in the course of the same procedure to suture or free the damaged tendons and nerves of the remaining fingers.

When the ring finger was severely damaged a similar procedure was employed. The finger was amputated and the little finger with its metacarpal bone transposed to the base of the fourth metacarpal.

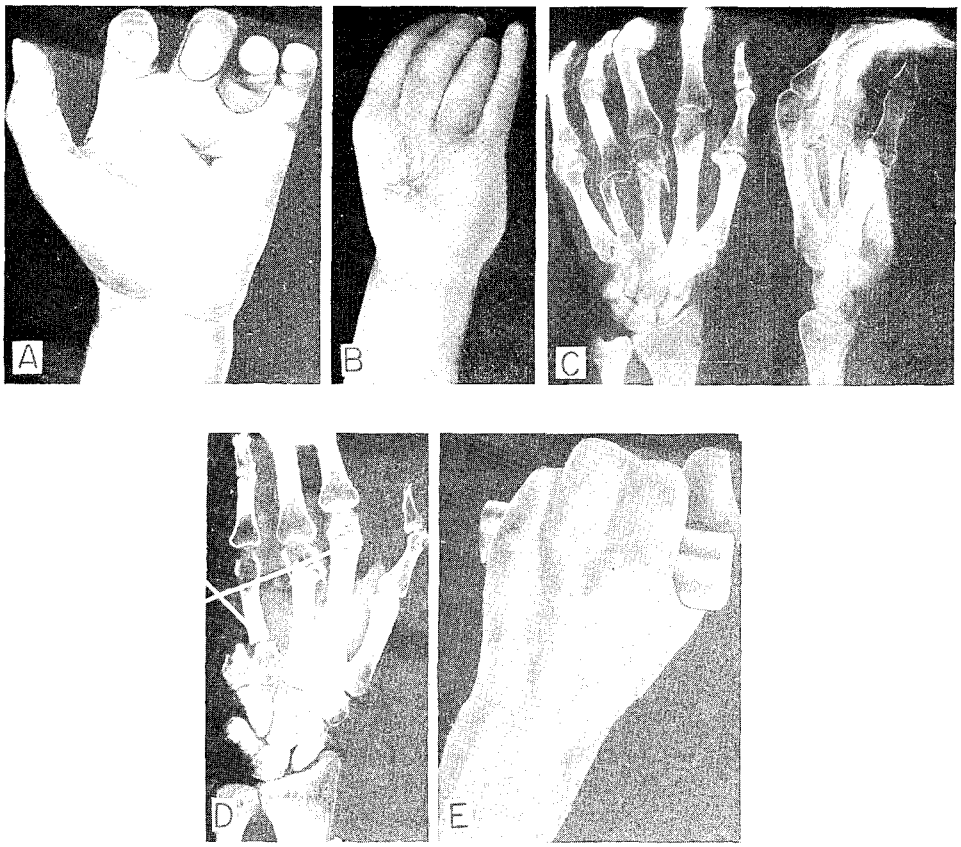



*Figure 205. A–C. Clinical and roentgenologic appearance of bullet wound of left hand with severe comminution of ring metacarpal and contraction and scarring of soft tissue in this area. D and E. Roentgenologic and clinical end results of surgery consisting of amputation of ring finger, excision of scar tissue, and transfer of fifth metacarpal and little finger to position of fourth metacarpal and ring finger. It was then possible to close the scarred area on the dorsum of the hand without using a flap. The hand healed in an excellent position of function and almost complete flexion of the fingers was possible.*

Transposition of digits was carried out in 25 patients, in all of whom results were extremely gratifying.

## Amputation

Amputation of the entire hand was not necessary in any patient at the Valley Forge General Hospital. On several occasions a single finger was amputated because extensive scarring, loss of sensation, and the obvious impossi-

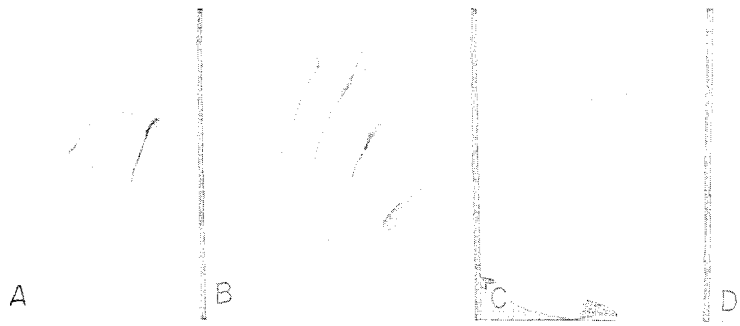



*Figure 206. A and B. Wound of left hand with extensive comminution of second metacarpal bone, damage to the corresponding metacarpophalangeal joint, and marked contracture of the soft tissue on the volar aspect of the fingers. The fracture of the second metacarpal was ununited. The index finger had rotated into the palm and function of the other fingers was inhibited. C and D. End results of surgery. The index finger was so severely damaged that it quite evidently could not be restored to any useful function. This finger and the distal two-thirds of the metacarpal were therefore amputated. The intrinsic muscles were hooked up to the radial side of the proximal phalanx of the middle finger to give it stability. This procedure resulted in almost complete function of the remaining portion of the hand and also produced a satisfactory cosmetic result.*

bility of restoring function made it a useless member (Fig. 206). The stumps of amputated fingers and painful stumps were also frequently revised.

When amputation of the index finger was necessary it was the usual practice to resect the distal third of the second metacarpal also. On many occasions a portion of the finger amputated was used as a flap to fill in a scar defect in the web area of the dorsum of the hand. When the head of the third or fourth metacarpal had to be removed the transposition operation was usually done. When a portion of the finger had to be amputated the flexor or extensor tendons were never sutured. The flexor tendon was cut well up into the palm of the hand so that the stump would retract. If the distal portion of the finger was amputated the sublimis tendon was left intact so that it would control the proximal interphalangeal joint.

## REHABILITATION

Rehabilitation of an injured hand was always important and frequently difficult. In all patients in whom it was practicable, it was the general rule to institute early motion and mobilization by activity and steady traction. Elaborate mechanical splints and appliances were not used for this purpose. A knuckle bender of the Bunnell type (Figs. 6 and 7) was employed extensively for mobilization of the metacarpophalangeal joints.

A traction glove, consisting of a wrist band with traction applied over the ends of the fingers in order to pull them toward the wrist, was used for mobilization of the two distal joints (Fig. 207). A band was frequently placed over the fingertips and about the dorsum of the hand to secure a greater flexion pull. Flexion contractures of the joints were frequently corrected by plaster splints with extension wires to which rubber band traction was applied. This type of traction was furnished by a small leather cuff slipped over the finger, from which fairly heavy rubber bands extended to an outrigger wire (Fig. 124); the amount and direction of pull could be altered as was necessary.

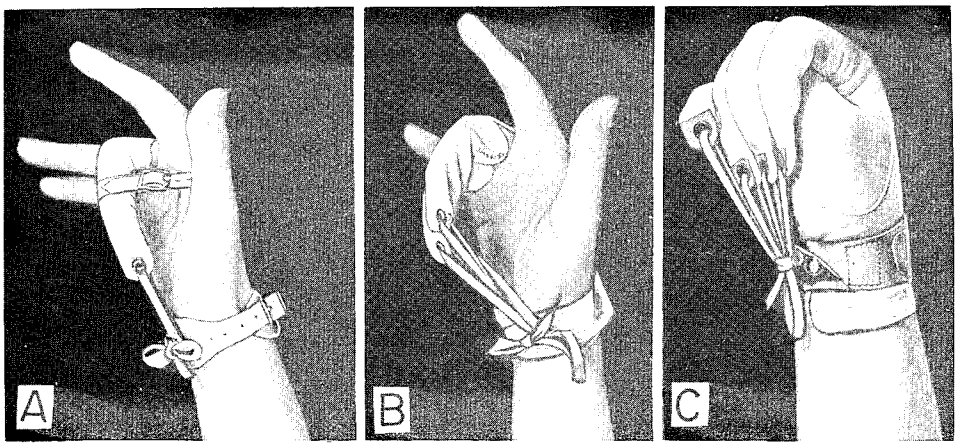



*Figure 207. Traction glove used to secure flexion in two distal joints of fingers. It could be used on 1 (A), 2 (B), or all (C) fingers.*

For extension of the fingers a plaster splint was made on the dorsum of the hand; a wire outrigger protruded beyond the ends of the fingers, and traction was applied in the desired direction (Fig. 208). The splint was carried either to the metacarpophalangeal joint or to the interphalangeal joint, depending upon the joint in which mobilization was indicated. This splint was also used for traction to pull the thumb into adduction or abduction, as required.

Traction alone was not adequate in contractures associated with adherent tendons; in these cases surgery was also necessary.

In the rehabilitation of the injured hand occupational therapy played an extremely important part. The patient was assigned a job on the basis of his needs, not just to keep him working. The occupational therapist knew the results desired and devoted her efforts to restoration of the special function which had been lost. Physical therapy was used as a stepping stone to occupational therapy, or for patients in whom muscle training and re-education of muscle function were necessary. It was the custom at Valley Forge General

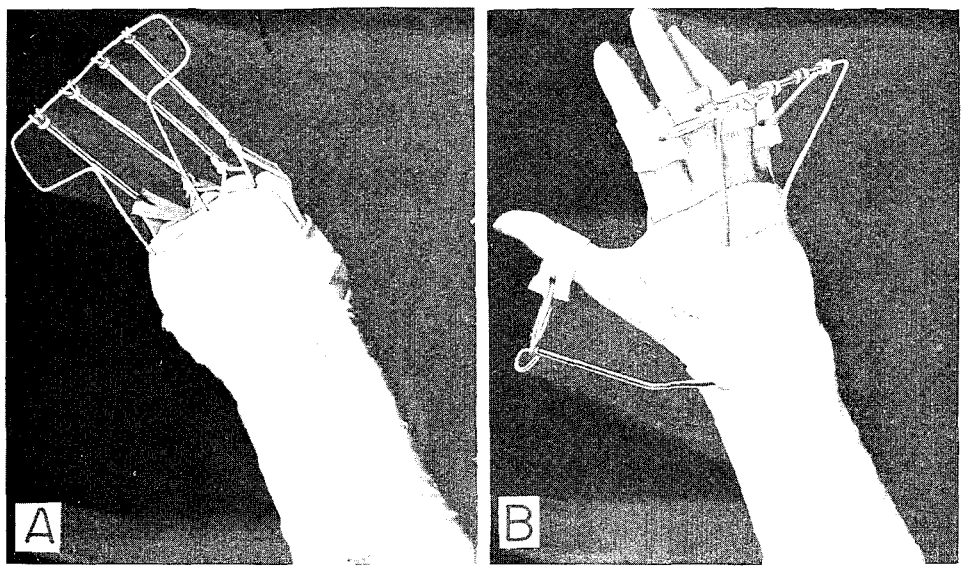



*Figure 208. Plaster splint applied to dorsum of hand for extension of finger. A. Splint carried to metacarpophalangeal joint. B. Splint carried to interphalangeal joints. Note that this can be used to adduct or abduct the thumb, as desired.*

Hospital to consider physical therapy and occupational therapy as one, and to describe them under the term of physical medicine without differentiating one from the other.

## CONCLUSIONS

The end results of hand surgery and of subsequent rehabilitation cannot be determined within short periods of time; nor can results of tendon suture or nerve graft be fully evaluated until at least 2 years have elapsed. Stereognosis does not return for a year at least, and the interval is much longer if the nerve has been damaged at a high level.

The results of the procedures described proved for the most part extremely gratifying during the period of time the patients were observed at Valley Forge General Hospital. It was noted repeatedly that a soldier with seriously injured hands could be returned to a useful occupation. That was the objective of all treatment.

There were no facilities at this hospital for the fitting of prostheses to hands. From the standpoint of both physician and patient this was probably an advantage. Neither could be contented with substitution of artificial appliances for natural function. Both were interested, therefore, in carrying rehabilitation to the point of functional usefulness.

CHAPTER XIV

# Hand Surgery at Wakeman General Hospital

*Lot D. Howard, Jr., M. D.**

## ADMINISTRATION

Hand injuries were cared for on a subsection of the general plastic section. Patients with these injuries were kept on separate wards and for all practical purposes the hand service was managed as a separate unit. The subsection was under the direction of a single medical officer experienced in this field who had assigned to him from 1 to 4 other medical officers, as the needs of the service required. By reason of the close liaison maintained between the officer in charge of hand cases and the chief of the plastic section, special surgical or administrative problems were readily settled. Surgical work on the hand, whether it involved the skin covering, the tendons, nerves, joints, or bones, was carried out by officers of the subsection. If neurosurgical or orthopedic consultations were desired they were obtained according to regular Army routine. Most came from the neurosurgical service and concerned problems of splinting or tendon and bone injuries. Patients were accepted as transfers only when the neurosurgical service had practically completed its aspect of the case. Patients with acute hand infections were promptly transferred to the hand service, or hospitalized if seen in the outpatient dispensary.

## QUALIFICATIONS AND TRAINING OF PERSONNEL

Officers in charge of the hand subsection were usually chosen by the Civilian Consultant in Hand Surgery. Qualifications for the position consisted of general surgical training, usually special training in orthopedic or traumatic surgery, frequently training in plastic surgery, and always an interest in the problems of reconstruction of the hand.

Medical officers who served under the chief of the hand subsection were usually general surgeons. Some had had varying amounts of orthopedic training, but for the most part these officers were younger men without previous training in surgery of the hand or in any type of reconstructive or peripheral nerve surgery. The amount of surgical work on the hand which they could perform when first assigned was extremely limited and a training period of 6 months, at a minimum, was necessary before they could begin to do any major work. By that time they were usually in line for transfer to other positions and were replaced by inexperienced officers.

*Assistant Clinical Professor of Surgery, Stanford University. Formerly Lt. Colonel, MC, AUS.

From time to time officers from other Army installations were sent to this hand center for periods of training lasting from 2 weeks to 2 months, the objective being to provide them with sufficient skill to permit them to do hand work at their stations. The basic aim of the course was to teach them how to examine a hand; how to visualize the causes within it responsible for limitation of function or sensation; and how to conceive what could and could not be done in the way of reconstructive surgery. Special emphasis was placed on the futility of attempting reconstruction when too much was wrong with the part. An essential phase of the course was a general review of the normal anatomy of the hand, especially in respect to the motions and functions which each structure carries out. The officers in training were utilized as assistants in surgery and were taught and quizzed during operative procedures. Special stress was placed on postoperative care, and endeavor made to see that each officer followed specific cases throughout the preoperative, operative, and postoperative course.

## GENERAL MANAGEMENT OF PATIENTS

Patients admitted to the hand subsection were examined by the officer in charge who reviewed the previous history and roentgenograms. Results of the examination were recorded in the chart under the heading "Plan of Procedure." Entries included history of the injury, notes on previous care, present findings, diagnosis, and recommendations for further surgery or other treatment.

A roster board of patients was maintained, and an endeavor made to place them on furlough as soon as possible, and for as long as possible, after or between operative procedures. Priority of treatment was given to patients who had long been hospitalized, to those who needed nerve repair, and to those who required only minor procedures.

All patients were seen at intervals after operation by the officer in charge of the hand wards whose responsibility it was to guide the general progress of each case. Dispositions were made when it was felt that further medical treatment would not be needed, even if the maximum amount of expected improvement had not been attained. The reason for this policy was obvious: A repaired extremity could be expected to improve in function for a year or more after operation, and hospitalization for this length of time would be extremely undesirable.

## RECONSTRUCTION PROBLEMS

During the early months of the war many patients with hand injuries returned from overseas with unhealed wounds resulting from extensive loss of soft parts or infected fractures of the metacarpals or the carpus. Injuries in patients from the South Pacific area were mainly gunshot wounds from small caliber rifles used by Japanese snipers. A good many patients had self-inflicted

wounds, most of which were considered to be accidental rather than deliberate. No patient admitted he had wounded himself for the purpose of getting away from the battle area, although it seems reasonable to assume that at least some of the injuries observed had been acquired for this purpose (Fig. 209). Large dorsal cruciate scars were present in most of these wounds and interfered materially with plastic work. The reason for this type of surgical incision remained obscure.

When casualties began to return from the North African, Mediterranean, and European theaters, the hand injuries were much more severe. They were caused chiefly by fragments from high explosive shells. Injuries of this type, though for the most part healed, sometimes presented small sinuses which extended to bone. Silk sutures were frequently the cause of sinus formation and delayed the additional reparative work necessary. Wounds by small arms, other than the accidental variety, were quite uncommon. As the war progressed, most hand injuries were received in the Zone of Interior already healed. Split skin grafts or direct pedicle applications by means of the open or closed flap method had been used (Fig. 210).

The tissues were soft and mobile, and the joints generally quite limber in hands which had suffered extensive wounds but in which healing had occurred within a fairly short time. Those in which wound healing was delayed by active infection or prolonged edema, or had nerve lesions, showed marked stiffening and induration. Extensive hand wounds caused by shell fragments were associated with bony damage and deformity, sometimes of a surprising degree (Fig. 211). In but few instances was it evident that any particular care had been taken to correct bony alinement overseas; the emphasis there was laid principally on getting the wounds healed, which was probably correct.

Crushing injuries of the hand were occasionally encountered. They were generally the result of automobile accidents, heavy gun recoil, or similar causes. In all instances the hands, especially the finger joints, were exceedingly stiff.

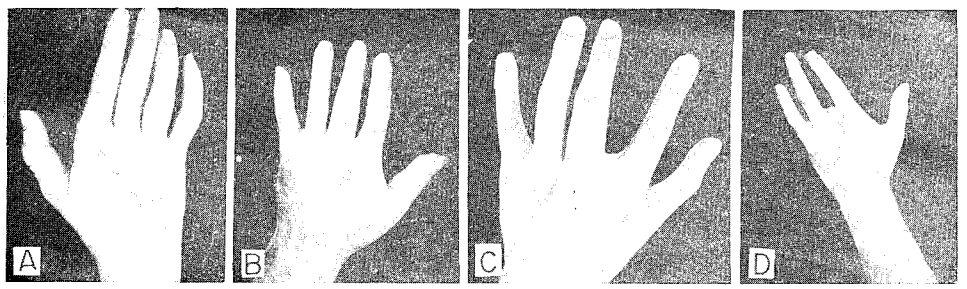



*Figure 209. A–D. Typical instances of self-inflicted wounds of the hand, sustained at close range in a battle area and reported as accidental. The dorsal cruciate incisions by which these wounds were managed resulted in scars which interfered materially with subsequent plastic surgery.*

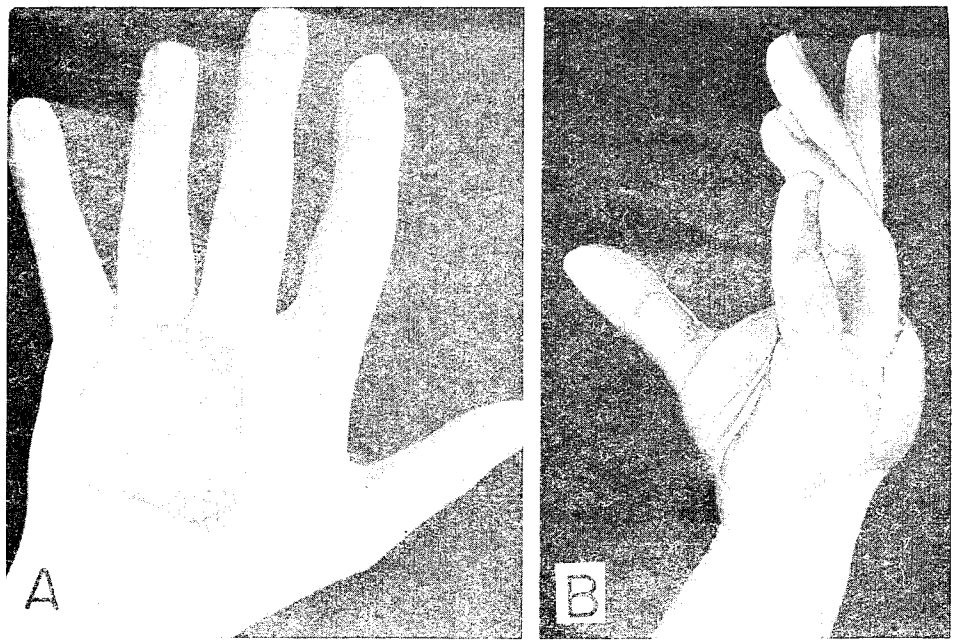



*Figure 210. A and B. Pedicle skin applied directly to an open wound in an overseas theater. Note the biscuit-like appearance of the skin, resulting from the transfer of excess fat, the circular configuration, and the contracting deep scar.*

Although fractures did occur, it was not uncommon to find roentgenograms showing bones normal except for osteoporosis and to find no scars to indicate a break through the skin. Men with this type of wound had often been held for long periods in hospitals overseas in the hope of early recovery, which never occurred.

## Corrective and Protective Splinting

Splinting was a very important procedure in the treatment of hand injuries and required close supervision of the medical officer in charge of the hand subsection. Splints had to be individualized or they would fail to embody the proper principles to obtain the desired correction. Temporary splints were often made by the ward surgeon with plaster of paris as a foundation, the attachments consisting of embedded wires or other metallic appliances.

The corrective type of splinting consisted of slow, steady traction in the proper direction, with care taken to avoid undue strain on joints not immediately involved.

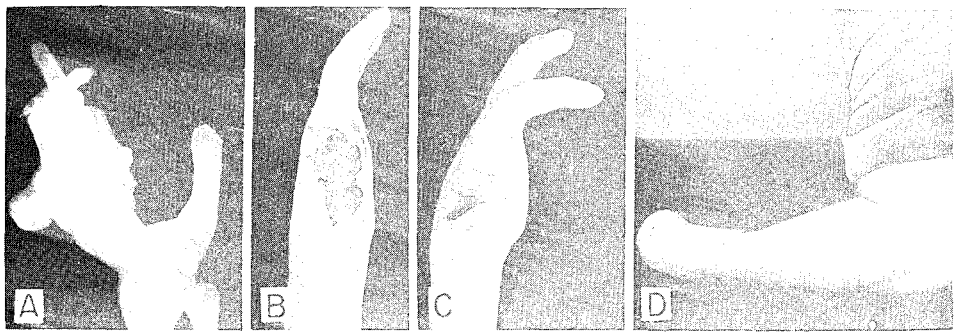



*Figure 211. Extremely severe wound of the hand resulting from injury by shell fragments. A. Roentgenogram of hand showing extensive bone disruption. B. Appearance of injury after necessary amputations had been performed overseas. When the patient reached the Zone of Interior hospital the wound was clean but was still unhealed. C. Healed wound after application of skin graft. Little improvement followed this step because of the excessive, deep scarring and the disruption of muscles, tendons, and nerves. D. Appearance of extremity after amputation through carpus, with utilization of the remaining palmar skin to cover the stump. A good stump was thus provided, with an adequate vascular bed distally, in contrast to the long forearm type of stump, which is likely to be blue and cold. Amputation was regarded as the solution of this injury because so much was wrong with the hand no method of reconstruction seemed feasible.*

After nerve and tendon suture protective splinting was especially important. After nerve suture maximum relaxation was maintained for at least a month. The affected part was then slowly extended until maximum stretch had been achieved. This often required a month of additional splinting, and sometimes more. Progress was always intentionally very gradual. Splinting was also maintained for a month after tendon suture or tendon graft since it takes approximately that period of time for solid union of tendon tissues to occur. When the limb was removed from the splint, motion with active voluntary exercises was begun. Resistive exercises, to build up strength in the muscle, were also done. Later, splinting was sometimes briefly resorted to in an effort to accomplish additional excursion of the repaired tendon. Occupational therapy was of special value, particularly in the provision of resistive exercises, but nothing accomplished such good results as active use of the extremity in some useful occupation while the patient was at home on furlough.

It was emphasized that regardless of the original cause of the stiffness forceful manipulation of any small joint in the hand was contraindicated. Prolonged forceful elastic splinting could cause equal damage to small joints. The damage incurred probably results from pressure atrophy of the articular cartilages. This observation was made over and over again in joints which had been treated by prolonged forceful traction.

## Burns

Burns of the hand in patients received from overseas were usually healed on arrival in Zone of Interior hospitals, split skin grafts having been used. In most only the dorsum of the hand was involved to a disabling degree. The resulting contractures varied greatly. In general, they were of the extension type for each joint, with resultant limitation in flexion of the joint. Not infrequently the burn over any one of the three finger joints had been so deep as to have destroyed the extensor tendon at this level. When this occurred, the joint invariably fell into the flexed position, in spite of the amount of dorsal scar. All types of deformity thus occurred, such as extension contracture of the proximal and distal joint with flexion contracture of the middle joint; flexion contracture of the proximal joint with extension contracture of the distal two joints; or other combinations involving any of the fingers. Often the resulting picture was bizarre (Fig. 212). The distal and middle joints, as a rule, were more likely to suffer loss of the extensor tendon than were the proximal ones. Were the burn deeper, the joint itself might be sufficiently damaged to ankylose spontaneously. When this occurred, it invariably fused in a flexed position. Often the nails were badly distorted and had lost their central bed. The resulting bivalve nails were difficult to care for and were unattractive cosmetically. In such cases, the nail with its bed was completely excised and the area covered by a split thickness (0.0020 inch) skin graft, with good functional and cosmetic advantage (Fig. 213).

If there were much scarring, thick split grafts were used to cover the dorsum of the hand. These grafts were generous, and particular attention was paid to the webs and to getting adequate, broad cover on the dorsum of

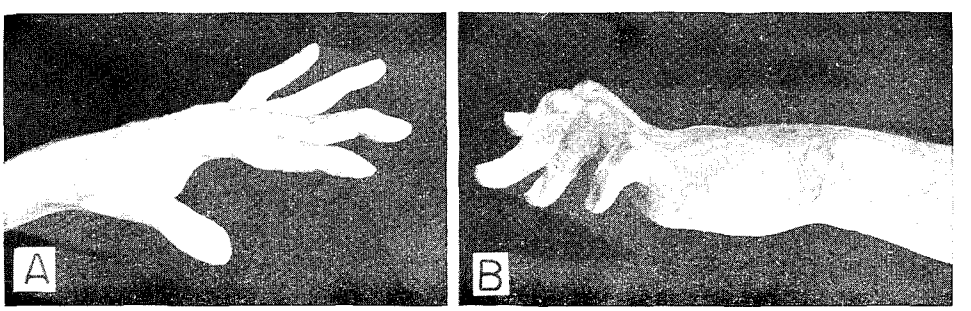



*Figure 212. Typical gasoline burns of the dorsum of the hand. A. Extensor contractures of the middle joints of the fingers resulting from excessive dorsal scarring. Note that the burn was not deep enough to destroy the extensor tendon over the middle joint. B. In this case the burn was deep enough to destroy the extensor tendon over the middle joint and produce flexion contracture. Extension contracture of the proximal joint was also present.*

the fingers at the time they were applied. Keeping the joints in the flexed position whenever possible assured that the maximum surface would be covered. In covered cases with residual extension contracture of the proximal joints it was possible to perform capsulectomies through the grafted skin, but care was exercised to avoid undermining. Volar burn scars could be replaced by full thickness grafts, provided that a subcutaneous pad was left (Fig. 214); otherwise, the pedicle method was better. In prolonged contractures it was emphasized that even the normal tissues remaining were foreshortened and that joints might suffer from intrinsic stiffness, as well as from limitation of the surface soft tissue.

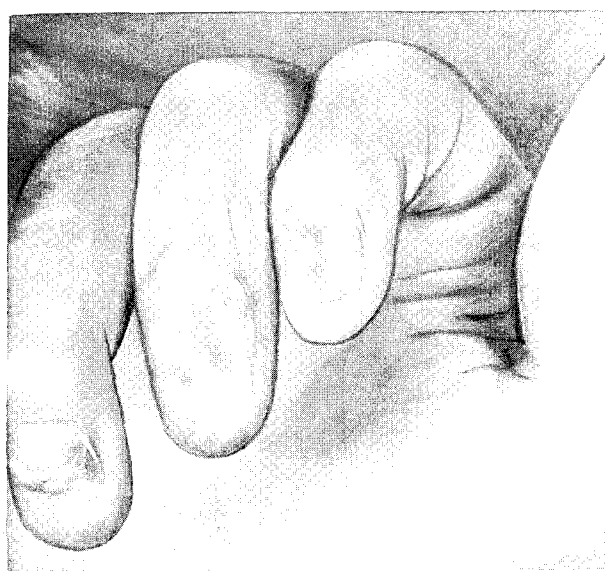


*Figure 213. Severe deformity of nails following a burn of the hand. The damage in this type of case can be completely eliminated by excision, including the nail bed and root and then covering the denuded areas by split thickness skin grafts. Index and middle fingers show the good cosmetic appearance resulting from this procedure.*

In unhealed burns of long duration it was thought better to use a thin split graft cover to obtain healing, and later to do the final grafting, at which time all of the scar could be removed.

Recent burns were treated by vaseline gauze, compression and immobilization until healing occurred. Constant early motion was not regarded to be of much value if it delayed healing. In such instances all that happened was that more scar was created.

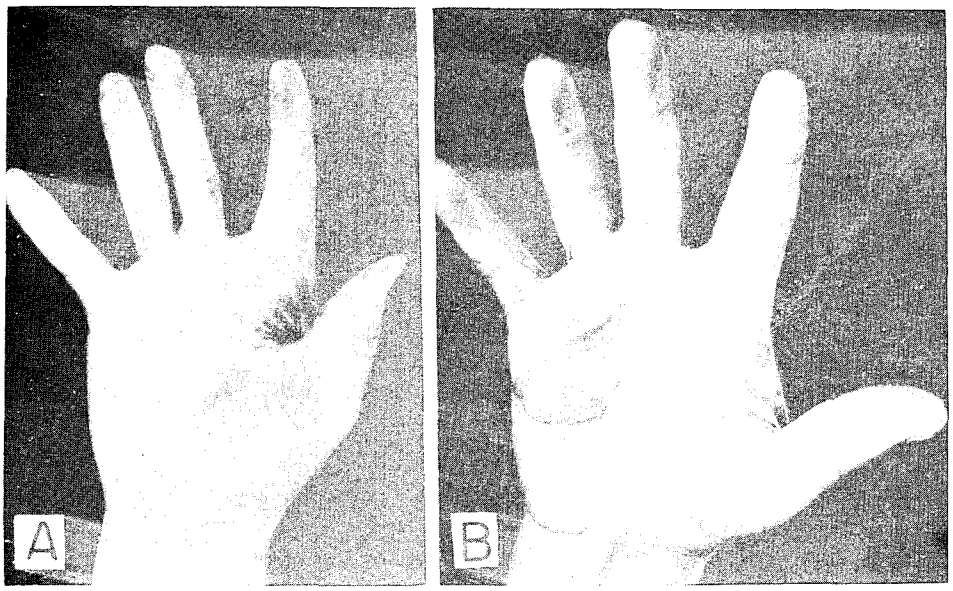



*Figure 214. Gasoline burns of volar aspect of hand. A. Volar scarring and contracture. B. Release of contracture by use of full thickness skin graft. This technique was possible here because of the good bed of subcutaneous tissue beneath the scar. C. Extreme volar burn of hand as result of phosphorus bomb. The damage was so extensive that amputations were necessary and marked contracture and scarring resulted, with loss of all subcutaneous tissue but not of flexor tendons and nerves. D. Correction of damage by excision of scar tissue, opening out of hand, and application of good skin and subcutaneous fat by the tube pedicle method. A Kirschner wire splint has been applied to maintain immobility during healing.*

## Healed and Infected Wounds

Healed wounds did not require immediate treatment; surgery was delayed until all induration of the soft parts had disappeared.

In infected wounds a satisfactory treatment was the use of wet boric or saline compresses which were changed completely every 4 hours. A daily soap and water cleansing further hastened healing. These simple measures were in addition to adequate drainage, elevation, and immobilization of the involved part. Sloughing soft-tissue structures such as tendon or fascia could be trimmed away to minimize the amount of bacteria-harboring material. As soon as the wound was clean and granulating, a split skin graft was applied immediately even though the wound was small.

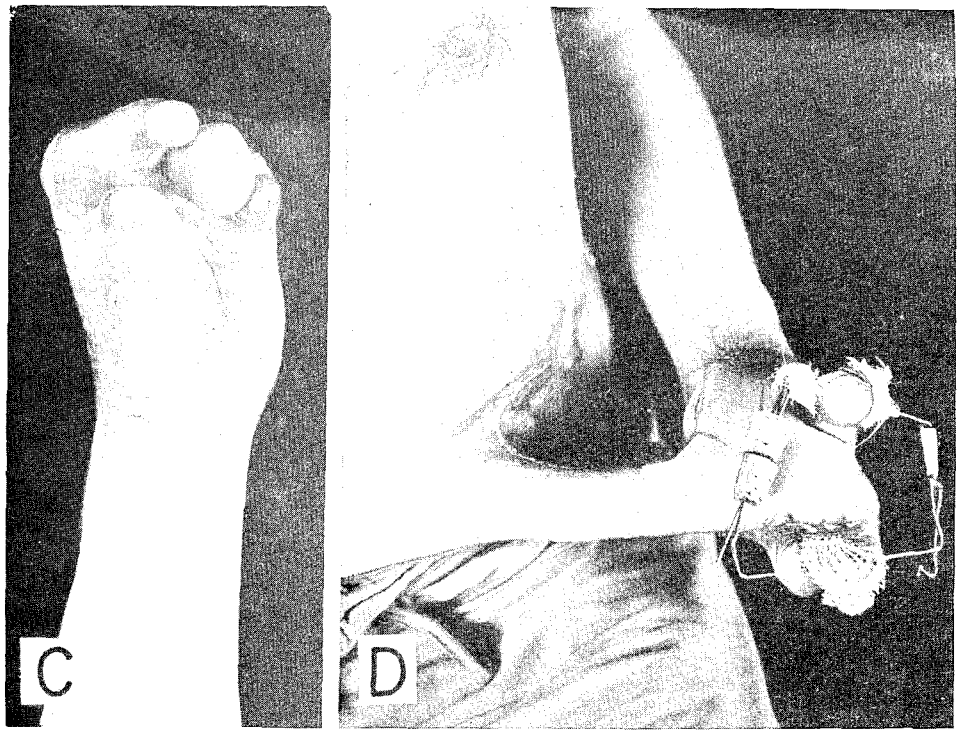



*Figure 214*—Continued.

## Skin Grafting and Skin Replacement

Skin grafting and skin replacement were carried out by the usual plastic methods. The only point requiring emphasis is that when skin replacement was done, especially when by the pedicle method, it was of utmost importance that all deep scar tissue be removed prior to the pedicle application. Excision of the scar permitted a view of the deeper structures and determination of the extent of injury. It was often possible to do at that time some corrective procedure such as a bone graft, a tendon suture or graft, or a nerve suture, or to overcome some of the gap in nerves, and thus make later suture easier. If aside from skin and subcutaneous replacement further work was not necessary, there was no reason to leave surplus fat on the pedicle to achieve viability of the skin; this practice necessitated at least two additional operations for defatting at the end of the procedure. When pedicle skin was to be placed into small areas of unusual shape or size a pattern of the defect at its maximum size was made and transferred to whichever end of the pedicle was to be used. The skin was cut according to the pattern before the pedicle was severed, ensuring a good fit, with the skin at proper tension. The denuded

area on the abdomen was either closed directly by plastic maneuver or readily covered by a split skin graft held in position by a stent mold. Skin free of hair was selected for pedicle grafts intended for the palm of the hand.

In all pedicle work, it was kept in mind that skin seldom dies from lack of arterial blood supply, but often from lack of venous blood return, which causes cyanosis, blistering, thrombosis, and gangrene. Uniform pressure dressings were regarded as necessary when there was the least embarrassment of return circulatory flow.

The closed-tube method of providing skin to the hand was preferred to the direct single-stage flap. The incidence of infection along the margin was thus lessened and a functional position of the extremity could be more easily maintained during the process of attachment. A generous allowance was made in applying any type of cover.

## Bones and Joints

### *Fresh Fractures*

Fresh fractures were seldom treated on the hand service; these were usually cared for through the outpatient orthopedic service. For such fractures, the method of treatment advocated by Böhler [1] proved extremely satisfactory. Open reduction was seldom necessary and even Kirschner wire fixation, though convenient, was not thought indicated as routine. Cases of Bennett's fracture which could not be adequately reduced by the closed method were best treated by open reduction and Kirschner wire fixation if a tendency to subluxation of the joint was present.

### *Nonunion and Malunion of Fractures*

The operative approach to these two conditions was dependent upon a survey of the function of the hand. In several instances of nonunion of metacarpals with much loss of metacarpal shaft when only the head remained as a distal fragment, there was such good mobility at the nonunion site that further corrective procedures were waived (Fig. 215). Metacarpal nonunion had to be treated by bone graft, preferably with spongy bone from the iliac crest. Bone from this site seemed to live more readily and to unite sooner than dense cortical bone such as is obtained from the tibia. A generous amount of bone was more satisfactory than a thin bridging of the defect. In some instances in which a sufficient distal fragment of the metacarpal was left, capsulectomy of the proximal joint done at the time of bone graft aided materially in achieving proper rotation and angulation of the distal fragment (Fig. 216). Nonunion of the phalanges generally required a key type of bone graft, though this was not applied unless the finger was worth saving in other respects.

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[1] Böhler, Lorenz: The Treatment of Fractures. Baltimore, Wm. Wood & Co., 1932.

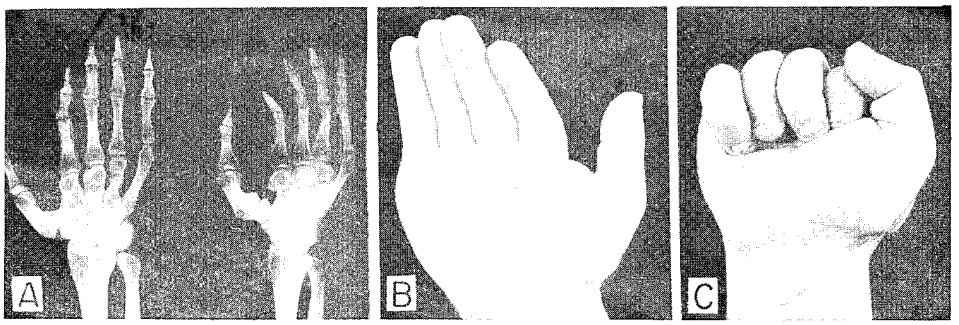



*Figure 215. Shell fragment injury of hand, with fracture, nonunion, and loss of substance of metacarpals of index, middle, and ring fingers. A. Roentgenograms showing extent of bony damage. B. Appearance of hand after healing by direct application of pedicle overseas. Note that the fingers are fully extended. C. Demonstration of range of motion in injured hand. Since motion was possible and was made with strength, further operative procedures were considered unnecessary.*




*Figure 216. Fracture of metacarpal of index finger. A. Roentgenograms showing nonunion and loss of substance. B. Correction of injury by iliac bone graft, with Kirschner wire fixation to maintain proper rotation and prevent amputation. C. Roentgenograms showing end result of surgery.*

Common sites of malunion were the metacarpals; the distal portions angulated volarward while the head of the bone formed a tender lump in the palm. In the proximal phalanges the distal fragment might be angulated dorsally as much as 90 degrees. The latter deformities were often the result of tank-hatch injuries. Even though the finger joints were free and the flexor tendons active, a satisfactory fist could not be produced. In severe cases wedge osteotomies of the proximal phalanges to correct the angulation were employed. To minimize postoperative adherence of the extensor and flexor tendons at the site the procedure had to be done gently. Osteotomy could be combined with a bone graft when the latter was indicated. The same procedure could be applied to malunited metacarpals.

One very common and disabling bony injury was the dorsal dislocation of the metacarpals on the carpus. In some instances part or most of the distal

carpal row had dislocated with the metacarpals. The result was an alteration of the mechanics of the hand; the metacarpals angulated volarward, the proximal finger joints were in hyperextension while the thumb web was relatively reduced; the dorsal hump might block dorsiflexion of the wrist, and the grip was weak. A true lateral roentgenogram was needed to show this condition clearly; correction was indicated and often a bone graft was needed (Fig. 217). After operation patients generally experienced an early sense of increased strength in the grip.

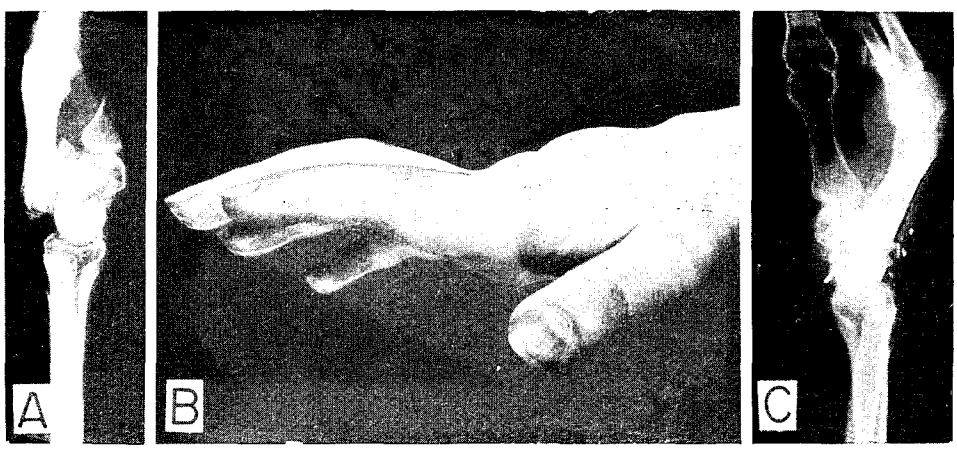



*Figure 217. Metacarpal dislocation. A. Roentgenogram showing dorsal dislocation of metacarpal bases before reduction. B. Clinical appearance of hand before reduction. Note displacement of metacarpal heads into palm and resultant deformity which has destroyed the muscle balance and produced a mild claw hand. C. Roentgenogram after reduction.*

Many perforating wounds in the proximal part of the hand were accompanied by deep motor ulnar nerve paralysis to the radial side of the wound. Longstanding intrinsic palsy narrowed the hand as a result of atrophy of the interossei and made repair difficult and end results less satisfactory.

### Capsulectomy

Capsulectomy was used advantageously only on the proximal joints of the fingers. Good results could be anticipated in this area, provided cases were carefully selected. In some of the less serious cases the use of the knuckle-bender splint devised by Bunnell proved to be of great value and obviated the necessity for surgery.

Capsulectomy on the proximal joints of the fingers consisted of complete excision of the collateral ligaments through short incisions between the knuckles. Care was taken to preserve the interossei tendons and the transverse bands of the extensor apparatus.

In a few cases in which there had been marked prolonged hyperextension of the proximal finger joints with resulting paralysis of the interossei and subsequent contractures the interossei tendons lay dorsal to the joint axis; they thus served to maintain extension fixation of the joint and had to be severed before it could be flexed. In these, if nothing else was done, the fingers invariably showed a strong tendency to drift ulnarward, as happens in an arthritic hand.

In many cases in which capsulectomy was indicated, adherence of the long extensor tendon served as a checkrein to flexion, and the joint was unable to come down until the tendon had been freed. In the smaller joints of the finger the volar capsule was occasionally excised for flexion contracture; results were usually poor.

Treatment after capsulectomy consisted of maintaining the proximal joints in flexion, usually by means of a leather sling about the proximal segments, and rubber band traction as advocated by Bunnell. Motion was permitted when all wounds were well healed; traction was used only to prevent the joint from going into extension again too early.

### *Bone Grafting*

Most of the bone grafting consisted of replacement of metacarpal losses in the presence of nonunion. This was accomplished by using iliac bone with Kirschner wire fixation, followed by the application of a cast. After some 2 months there was generally evidence of union and pins could be safely removed.

In taking the graft, the incision was made to lie about an inch below the crest of the ilium, to keep the scar off the bony prominence. The iliac bone was denuded on its outer surface. An osteotome cut was made along the crest but did not involve the anterior superior spinous process; this permitted reflection of the ridge with its abdominal muscle attachment; the tailoring of the graft in part could then be done in situ, which was advantageous. In closure of the wound the ridge was replaced to keep the normal bone contour. A thin inner plate was also left when this was feasible. Oozing from the bone was controlled by fibrin foam. Closure was accomplished by three rolling No. 30 stainless steel sutures, which were later tied over a bolster after the skin edges had been approximated with a running No. 36 or No. 38 stainless steel wire.

### *Osteomyelitis*

If there was extensive, active osteomyelitis of the phalanges secondary to acute infection, early open amputation was usually the treatment of choice. In chronic osteomyelitis secondary to compound fractures, response to adequate drainage and removal of sequestra was generally prompt. Some difficult problems occurred in infected wounds through the metacarpal and carpal areas. These were best treated by adequate dorsal drainage and the closed vaseline pack

method. As soon as the bone was covered by granulations, usually within 2 or 3 weeks, healing could be hastened by changing to the clean compress method. In some instances split skin grafts were placed into the cavities immediately after sequestrectomy; results were usually favorable. Elevation of the extremity during treatment was important as it minimized the amount of swelling of the hand and the eventual small joint stiffness. An airplane splint far exceeded in efficiency any type of sling.

#### *Arthroplasty*

One of the most difficult problems was the treatment of stiff finger joints, that is, of the interphalangeal and metacarpophalangeal articulations. A distinction was made between the stiffness resulting from specific injury and that occurring as a result of nearby wounds. In the latter category, immobilization was usually regarded as causing joint stiffness and it sometimes actually was responsible. Immobilization in itself, however, did not as a rule stiffen joints to a point where recovery in a reasonable length of time could not occur. The added factor of prolonged swelling as a result of dependence, a constricting cast, prolonged infection, or lack of nerve supply, caused fibrous thickening about the joint and general scarring and induration of the soft parts, or loss of elasticity of ligamentous structures.

*Metacarpophalangeal Joints.* Since they were frequently in extension during the time when the stiffening process was in effect the metacarpophalangeal joints were often most severely affected. The collateral ligaments contracted and shortened in their relaxed position and would not allow flexion. If conservative measures failed, a satisfactory result could usually be obtained by excision of these thickened collateral ligaments. When there was direct injury to the metacarpophalangeal joints with resulting disruption of the articular surface or complete loss of the joint itself through loss of the bone ends, surgical correction was generally necessary. Exceptions occurred when absence of the metacarpal head, or absence of the base of the proximal phalanx, or loss of the metacarpal shaft near the head, had allowed sufficient space; in effect, a traumatic arthroplasty had been performed. Associated tendon or soft tissue scarring often limited voluntary, and sometimes passive, motion in such traumatic arthroplasties, and soft tissue reconstructive surgery was necessary to provide the power to move the abnormal joints. It was uncommon to find spontaneous arthrodesis of the metacarpophalangeal joints as a result of war wounds.

When surgical arthroplasty was undertaken in the metacarpophalangeal joints, best results were obtained when the soft tissues about the joint were as near normal as possible and when there were good metacarpophalangeal joints of the digits at either side of the one operated on. In general, better results were obtained when adequate space was made between the bone ends.

When one or the other bone end had a fairly normal cartilage cover it was usually left in situ and fascia or soft tissue placed over the bone which had been resected. In one instance, an attempt to do arthroplasty by the use of a cap of tantalum foil over the resected metacarpal resulted in good range of motion at the end of about 3 weeks, but at the end of 2 months, the amount of motion was markedly restricted and the joint was thickened and limited by increase in scar tissue. Since foil had been used, there was not as extensive resection of bone as would otherwise have been made, and this in itself could have been a factor in the poor result.

In another patient,[2] arthroplasty of all proximal finger joints was undertaken because of destruction of all metacarpal heads as a result of a transverse perforating bullet wound. The metacarpal heads were resected and a vitallium biconcave plug inserted in each space. Healing per primam resulted. Approximately 6 weeks later, the plugs were removed at a second operation. It was noted then that they were entirely free and that the surrounding soft tissues had formed a smooth lining grossly similar to the lining of a bursa or tendon sheath. The immediate result in this case seemed very good, and sufficient motion persisted for the patient to be discharged in another month or two. No follow-up report was obtained, but it is reasonable to assume that a good range of motion continued. This procedure, while it does require staged operations, is much shorter than the one requiring capping of each bone end with a fascial hood.

*Interphalangeal Joints.* In cases of interphalangeal joint trauma there was usually marked restriction of motion and in most instances pain in the joint, especially when motion was forced. Frequently there was angulation, often with some rotation deformity at the joint as well. The joint was usually in almost full extension. The combined effect of these deformities was the creation of a stiff finger which was in the way when attempt was made to close the hand. Because of previous civilian experience and observation, arthroplasty of an interphalangeal joint was not done and operations on these joints were avoided unless some extremely simple procedure such as removal of an exostosis close to the joint margin in an otherwise roentgenologically normal-appearing joint, was feasible. In cases in which interphalangeal arthroplasty is done the joint is likely to be sore, to lack lateral stability, and to have little motion.

*Arthrodesis.* As an alternative to arthroplasty, the policy of arthrodesing interphalangeal joints damaged by trauma was followed. Effort was made to shorten the finger and to give fixation in a slightly flexed position. If sufficient bone surface for a good contact was present, end-on or side-to-side junction was accomplished by using very fine stainless steel wire or crossing small Kirschner

[2] This patient was observed at Percy Jones General Hospital, where surgery was performed by Lt. Col. Francis M. McKeever, MC.

wires, either buried or protruding, for fixation. If necessary, a bone graft was added. Union could be expected in approximately 2 months; by that time the flexor tendon usually glided freely past the resected joint. Voluntary extension of the distal interphalangeal joint was generally lost, but this function was often absent prior to surgery, and if passive extension was present the disability was slight.

Spontaneous arthrodesis of interphalangeal joints was seen quite frequently in patients with dorsal burns. The joint was almost always flexed, usually at or near 90 degrees, since the extensor tendon was destroyed before the joint fused.

*Thumb Joints.* Arthroplastic procedures on the metacarpocarpal joint of the thumb resulted in fair motion. As far as the proximal and distal thumb joints themselves were concerned, arthrodesis in a functioning position was the usual procedure when there was good mobility of the metacarpal. Arthroplasty of the proximal or distal thumb joint was not done at Wakeman General Hospital because it is very difficult to gain flexion and extension without loss of lateral stability. One patient had what amounted to an arthroplasty of the distal thumb joint as the result of infection of the joint in civil life several years prior to Army service. The end result in this case was a loss of the distal end of the proximal phalanx of the thumb without loss of either the long extensor or long flexor tendon; thus, in effect, an arthroplasty was produced. There was a full range of flexion and extension in this flat joint, but lateral stability was lacking. If the patient grasped a large object and that object was moved back and forth through the hand in a transverse plane, the distal thumb joint would make a lateral excursion with the object for a total distance of almost an inch. Although this excursion seemed to be a handicap, the patient regarded it as unimportant.

## Nerve Suture and Nerve Grafts

The results of nerve suture within the hand proper were usually gratifying, with good recovery of sensation. Recovery of motor function occurred frequently, but with considerably less regularity. It was also short of perfection by a considerable margin, probably because of secondary changes in the muscle and nerve-end organs. The two prime principles, i. e., accurate approximation in a bed of normal tissue, and splinting for sufficient time to ensure healing, were always emphasized, but no new technical methods of nerve suture were devised.

Nerve grafting was done frequently, with good results. The grafts required were small and were, therefore, likely to live as free grafts.

### *Sequelae of Nerve and Vascular Injuries*

There was wide variation in the clinical picture of the sequelae and in techniques for handling nerve and vascular hand injuries. Too frequently these patients were seen late on the hand service, after severe contractures and joint stiffness had already occurred. The recovery time was so prolonged in certain nerve lesions that reconstructive surgery was often not believed indicated for a matter of 1 to 5 years. The usual picture consisted of flexion contracture of the wrist, extension contracture of the proximal finger joints, and a severe clawed and flat hand. Another type of deformity was flexion contracture of the proximal finger joints, sometimes with the thumb metacarpal in opposition, adduction, and flexion, so that the thumb lay well in the palm of the hand, where it remained fixed. This peculiar contracture was associated with a history that the wrist had been maintained for a prolonged period in strong dorsiflexion after the injury. On analysis of such a contracture it became apparent that the deformity was caused by intrinsic hand muscle contracture secondary to the nerve paralysis of these muscles or to ischemic changes. Occasionally one saw isolated opponens and short flexor contracture of the thumb associated with a scar on the volar surface of the carpometacarpal junction; in such patients there was a history of cast pressure at this site. The muscle at operation was likely to be found very pale and very much scarred. The clinical picture and findings strongly suggested an ischemic type of contracture (Fig. 218), possibly from obliteration of the anterior palmar artery by pressure.

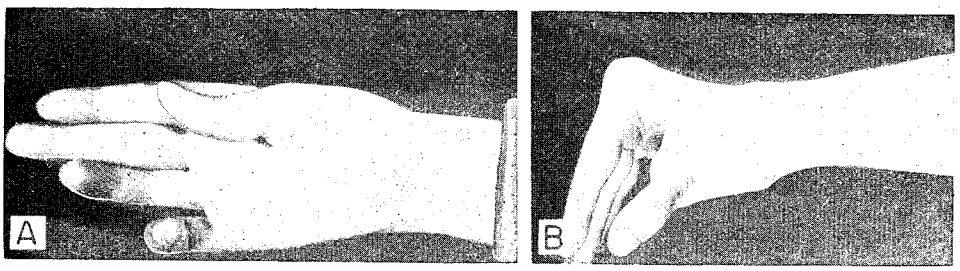



*Figure 218. Ischemic contractures. A. Localized ischemic contracture of intrinsic muscles of thumb which is held immobile and so far into palm as to prevent full flexion of index and middle fingers. B. Severe ischemic contracture of all intrinsic hand muscles. Note limitation of extension of proximal joints of fingers, with full extension of two distal joints. In this case a piece of pedicle skin has been placed in the palm, apparently under the mistaken impression that the skin was the source of the contracture.*

## Tendon Replacement

It was always interesting to note how much damage could occur from missiles while the tendons remained intact, though they were often damaged

and bound down at the site of injury. When there was a gap, replacement by free tendon graft could be made provided the involved joints were limber. The stainless steel pullout suture was ideal, but when there was limited mobility of the tendon other than in a straight line, as in the middle of the palm or above the wrist, buried steel sutures were definite timesavers if there was much work to be done at one operation. The double right angle stitch was generally employed.

## Amputations

When the amount of damage was great extensive reconstructive procedures for fingers were not thought warranted. Amputation at an early date was the procedure of choice. This was especially true when there was involvement of single digits other than the thumb and, in the case of right handed persons, when minor fingers on the left hand were affected and vice versa. A good amputation stump was quite satisfactory, and to obtain it all that was necessary was adequate cover, with displacement of the volar digital nerve ends away from the area of trauma or scar. Amputations through the joints of a finger, except the proximal joint, were generally unsatisfactory because of the bulbous, uncosmetic appearance of the stump.

A common error was failure to free the long profundus flexor tendon in stumps of the long, ring, and little fingers, with the result that the tendon adhered within the stump and became limited in its excursion. This prevented full action of the long profundus flexor tendons of the remaining fingers. The sublimis tendons, which act independently, could be left for added flexor strength.

In selected cases in which amputation was considered because of metacarpal loss, the substitution operation of sliding the proximal phalanx into the hand and fusing it with the base of the metacarpal was used to preserve the width of the hand and limit the tendency of the adjacent fingers to cross on flexion (Fig. 219). Amputation of a finger with its metacarpal might be indicated if the metacarpal as well as the finger was beyond repair. This procedure was particularly applicable for the index and little finger rays. In the former, it was especially advantageous when there was an associated thumb web contracture, as considerable space could be gained between the thumb and long finger.

As much length of thumb as possible was preserved. When the bone was present but had poor covering it was possible to provide adequate cover by pedicle skin or flap from over the index metacarpal. This was preferable to shortening the bone to obtain a good stump. When the thumb amputation was at the level of the proximal joint or distal to this level, building out of the thumb by a reconstructive procedure was not thought advisable.

When the amputation was through the proximal thumb joint, it was of decided advantage to deepen the thumb cleft by Z-plasty (Fig. 220) by which

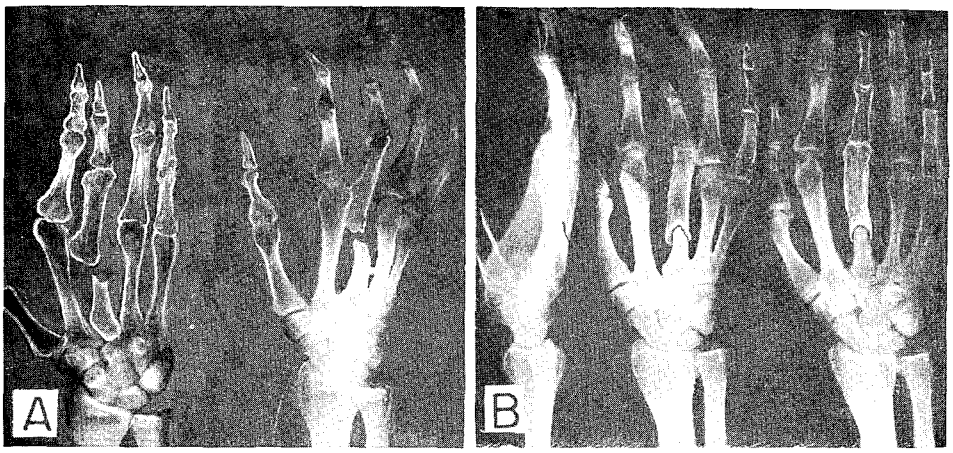



*Figure 219. A and B. Roentgenologic record of recession operation for loss of distal metacarpal with its head. In this case the finger was retained because it was useful. Otherwise, amputation through the middle finger joint would have been done.*

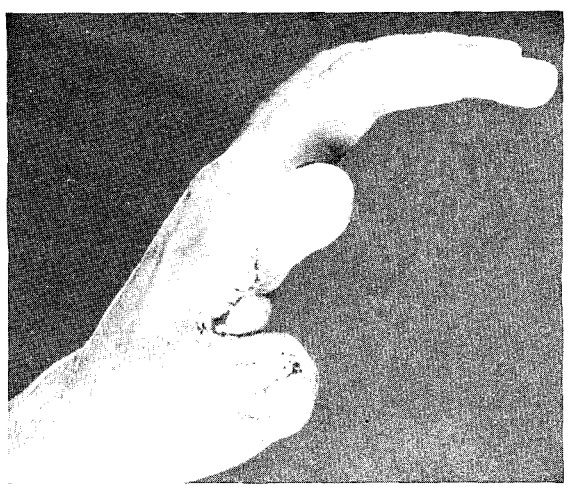


*Figure 220. Z-plasty to deepen cleft of thumb after amputation through proximal joint.*

a shelf is produced so that objects grasped do not slide off the end of the stump. When there was very little of the hand remaining, such as a single digit which had poor function and could not adequately be repaired, amputation was done through the carpus or proximal metacarpals, leaving a well-covered stump. Such a stump was covered by volar skin. Amputations through the wrist were not satisfactory unless volar hand skin covered the stump; otherwise the stump

was cyanotic and would not tolerate wear. In such cases forearm amputation was the wiser procedure.

In elective amputations, the finger skin, if intact and not damaged, was of value for covering scar tissue areas on the dorsum of the hand. In the case of the index finger, the tip of the finger when laid back could be made to reach as far proximalward as an inch above the wrist if the skin in the palm between the index and long fingers was split vertically, and a split graft was used to cover the resulting exposed side of the long finger (Fig. 221).

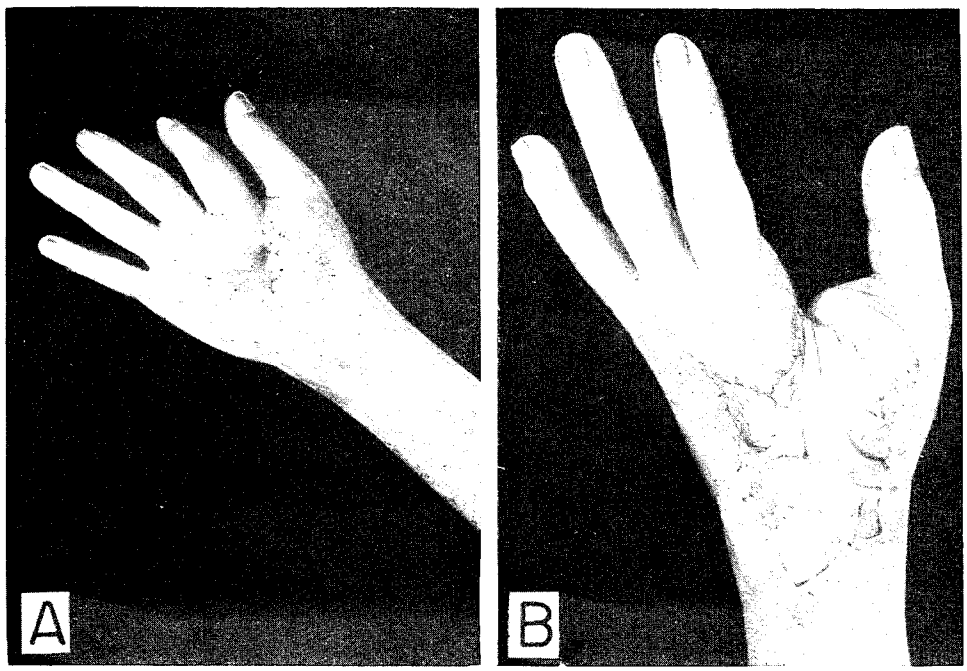



*Figure 221. Severe injury of dorsum of hand, with extensive scarring extending to wrist. A. Appearance of hand before surgery. B. Appearance of hand after plastic repair, which included utilization of skin of index finger for coverage. The index finger was not functionally salvageable in this case and the technique employed avoided the necessity for a tube pedicle or flap skin graft.*

## Reconstruction and Transplantation of Digits

These procedures did not usually prove worthwhile from the viewpoint of military service because the best results can only approximate the normal, and because so much time is required for the necessary surgery that the patient status is likely to outlast the war. Such operations were advantageous for some patients who were finished as far as future military duty was concerned but who would be benefited in civil life by these procedures.

As a rule, it does not pay to build out any of the fingers. Exception would be elongation in a case in which only one or two digit stumps are present. The problem thus limits itself to the thumb. The general rule followed at Wakeman General Hospital was that if only one thumb were missing, reconstruction was not attempted unless it seemed particularly applicable. If the entire metacarpal remained, extension of the thumb was not carried out; instead, the thumb cleft was deepened by Z-plasty or by other plastic methods. If the thumb had been amputated through the metacarpal, and if the thenar muscles were active and the carpometacarpal joint was good, extension of the thumb by pedicle and bone graft was of value. The extension was not made longer than the stump which would be represented by an amputation through the middle of the proximal phalanx. The construction of a post in cases of complete absence of the thumb furnished a useful short thick prominence against which the fingers could work. In other cases a prosthetic appliance (Fig. 222) served well and had the advantage of removability.

In the reconstruction of digits the tube pedicle method was generally used, with a free bone graft from the ilium or tibia as the strut for the extension. The graft could be placed after the pedicle had been attached or at the time

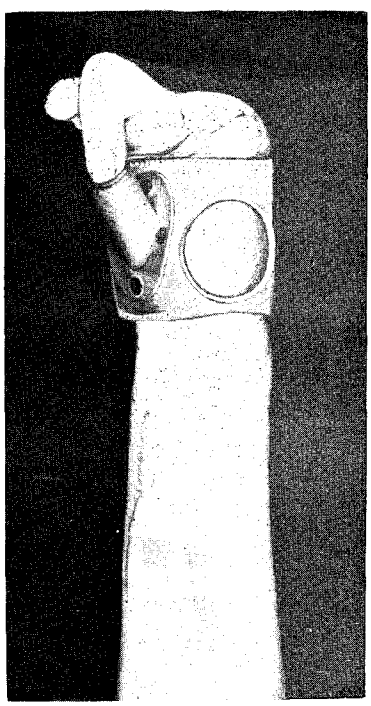


*Figure 222. Temporary prosthesis for thumb (constructed in orthopedic workshop, Wakeman General Hospital).*

it was attached, simply by making adequate room down the core of the pedicle to receive it. The use of stainless steel Kirschner wires for fixation of the graft was satisfactory. A Kirschner wire was also of considerable value in keeping the thumb cleft open during healing by transfixing the thumb and index metacarpal (Fig. 223).

Only one operation for transplantation of a digit was done at the Wakeman General Hospital. It involved the utilization of the long finger for a thumb which had been amputated through the metacarpal base. Transplantation was accomplished (Fig. 224) by making an abdominal pedicle and attaching it to the finger after amputating the finger through the middle segment, and opening it completely down the midline on the dorsum so that it provided a broad contact surface. An effort was made to preserve the flexor sublimis and extensor tendons and the volar digital nerves, so that they could be reattached to those of the thumb. The juncture was made by a saw-type approximation; circular scar constriction would thus be minimized as far as possible. After these various procedures had been completed, the patient was well satisfied with the end result; the surgeon was considerably less enthusiastic about what had been achieved.

Transplantation of toes, occasionally reported in literature, was not practiced at Wakeman General Hospital.

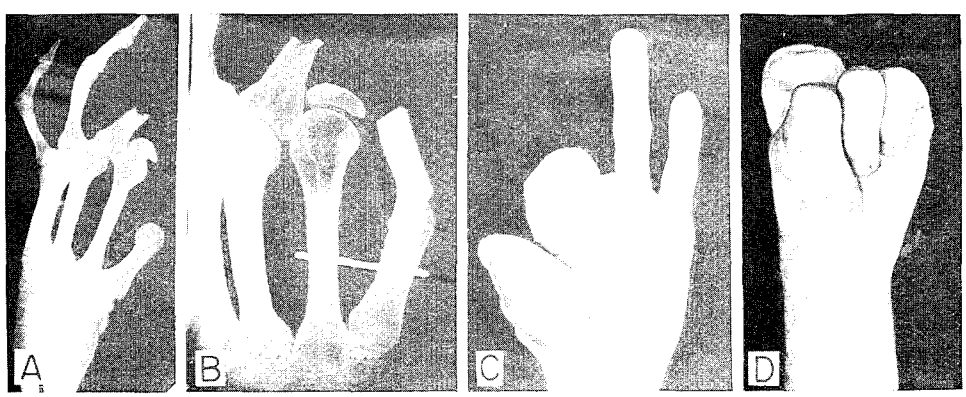



*Figure 223. Reconstruction of thumb by use of tube pedicle and bone graft. A. Preoperative roentgenogram. B. Roentgenogram taken after tailored cortical tibial bone graft had been placed. Note transfixion wires for graft and thumb cleft to maintain immobility during healing. C and D. Clinical end results.*

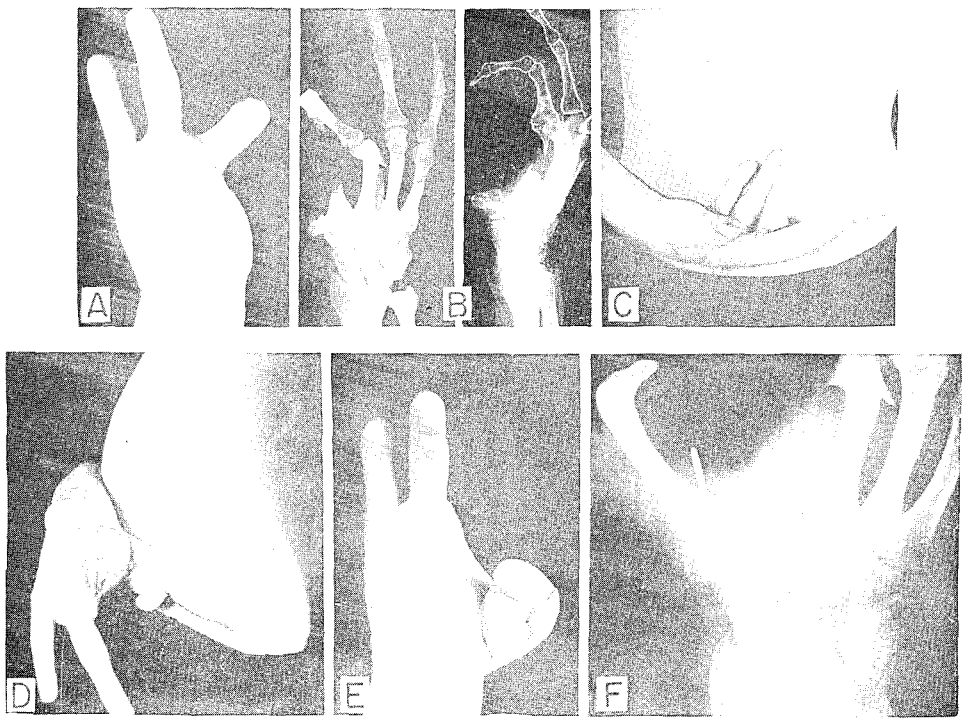



*Figure 224. Transposi.ion of digit to position of thumb with abdominal tube pedicle as conveyor. A. Preoperative appearance of hand. B. Preoperative roentgenograms. C. Attachment of abdominal tube pedicle along entire dorsal surface of middle finger. D. Movement of finger with pedicle to position of thumb. E. Digit in new location, after detachment of abdominal pedicle. The nerves and tendons have been reunited. F. Roentgenogram after transposition of digit. This patient was well satisfied with the end results of operation.*

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