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WCUND STUDIES IN PORCINE SKIN, MUSCLE
AND LIVER AS RELATED TO VARIATION OF
VELOCITIES OF SPHERICAL MISSILES

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**WOUND STUDIES IN PORCINE SKIN, MUSCLE AND LIVER AS RELATED
TO VARIATION OF VELOCITIES OF SPHERICAL MISSILES**

by

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SUMMARY PAGE

THE PROBLEM

To study wound ballistics in skin-muscle-skin and liver by gross and histologic techniques for application to a computerized casualty model. To delineate the extent of the temporary missile cavity by histologic methods. To determine energy absorption levels for skin-muscle-skin and for liver.

FINDINGS

1. Extent of gross and microscopic tissue changes was directly related to missile striking velocity.
2. The temporary cavity created by missile transit could not be delineated microscopically.
3. Energy absorption per centimeter of tract length was approximately equal in skin-muscle-skin and liver tissues.

ADMINISTRATIVE INFORMATION

This study was conducted at the request of the Ballistics Research Laboratory, Department of the Army, Aberdeen Proving Ground, Maryland, and funded by MIPR's RN801-73, RN837-73, and RN838-73.

The authors gratefully acknowledge the many contributions of Mr. R. Jackson, Mr. J. Quinlan, Mr. J. Moore (ballistics specialists); Mr. J. Hamby (histology technician); Mr. R. Rhoads, Jr., HM1 Buie (photographers); SSGT R. Stamer (veterinary technician); Mr. C. Eneix, Mr. A. Watkins, and Mr. N. Price (animal technicians).

The experiments reported herein were conducted according to the principles described in "Guide for the Care and Use of Laboratory Animals" prepared by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care, Institute of Laboratory Animal Resources, National Research Council.

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ABSTRACT

A study of wound ballistics in skin, muscle and liver was conducted with 6.35 mm spherical chrome-steel missiles projected at striking velocities of 400-1400 m/sec. Gross and histologic tissue changes are reported. Energy absorption per centimeter of tract length was found to be approximately equal for skin-muscle-skin and liver.

INTRODUCTION

Callender and French¹ in 1935, and Callender² in 1943 presented two classic articles on the study of wound ballistics that include experiments with bullets on pigs, goats, clay, and tin cans filled with water. Conclusions of these extensive efforts indicate that the factors of wound production are shape, weight, and velocity of the missile; density and character of the tissue; and direction and rate of transmission of energy. DeMuth³ states that susceptibility to injury is proportional to the specific gravity of the tissue involved and that muscle and bone are, therefore, especially prone to injury, whereas lung, a low density tissue, has considerable resistance. He notes that structures with a high elastic tissue content tend to resist injury, e.g., lung, skin, and blood vessels. Especially vulnerable are liver, spleen, and kidneys which may be literally shattered by bullets with only modest velocities. DeMuth^{4, 5, 6} gives a description of wounding related to velocity and bullet design, and presents an excellent review of the physical forces involved in the wounding mechanism.

Garrick⁷ states that low-velocity bullets often cause comminuted fractures of long bones but the degree of comminution does not approach that seen with high-velocity bullets. Herget⁸ notes that the explosive effects of the temporary cavity greatly accentuates the wounding potential of high velocity missiles. The missile transfers energy to the tissues within microseconds after impact and tissues along the wound tract expand laterally forming a cavity with high internal pressures and shock waves as high as 1500 psi.

Throughout these discussions of wounding mechanisms, it is emphasized that the significant factor in extent of injury is the amount of kinetic energy imparted to the tissue by the missile. Kinetic energy is derived by the formula, $KE = \frac{1}{2} \text{mass} \times \text{velocity}^2$, and it can be seen that if missile weight is doubled the energy is doubled, whereas if impact velocity is doubled the energy is quadrupled. There are also proponents of a "power" theory⁶ wherein $\text{power} = \text{mass} \times \text{velocity}^3$ and here velocity plays an even more important role than in the kinetic energy equation. In either event, missile velocity is a significant determinant of extent of damage.

These observations and theories by several investigators confirm that there are gaps in our knowledge of wounding by high velocity missiles. This laboratory has historically had an interest in personnel protection which, combined with a current need for a computer casualty model has led to several investigations. The first of these was a study attempting to delineate by gross and histologic techniques the extent of the temporary cavity in skin and muscle resulting from perforating missiles at various velocities. Secondly, there are a number of references to an explosive effect of high velocity missiles, both in tissue and in gelatin blocks. We propose that a specific tissue is capable of absorbing an amount of energy that is dependent on the physical characteristics of that tissue, and if that amount of energy is exceeded, an explosive effect occurs and the tissue no longer retains its gross anatomic integrity. Preliminary exploratory efforts have, therefore, been conducted into defining this "explosive threshold" for muscle and liver tissue.

MATERIALS AND METHODS

Pigs of a sufficient body size (130-150 lbs) to afford a thigh muscle mass comparable to man were utilized. A pre-anesthetic dosage of ketamine hydrochloride at a rate of 7-10 mg/kg of body weight was injected intramuscularly in the shoulder. General anesthesia, with sodium thiamylal in a 4% aqueous solution was administered intravenously (ear vein) in quantities sufficient to maintain the animal in deep surgical anesthesia. The animal was placed on a v-shaped board on its back and a rear limb was suspended from a horizontal bar above the animal.

A barrel with a smooth bore of 7.62 mm diameter was rigidly bolted to a mount frame which could be moved at will. The projectile fired from the barrel was a 6.35 mm grade No. 25 chrome-plated steel ball with a weight of 16 grains (1.036 gm). The steel spheres were mounted in a phenolic resin sabot, measuring 7.62 mm plus 0.000 minus 0.001. As the sabot left the barrel, it shattered; therefore, a steel plate deflector was placed 10 cm from the end of the barrel with an aperture of 1 cm to allow the sphere to pass through but retain the resin particles. Two sets of ballistic screens were utilized to determine the missile velocity (Fig. 1). The first set determined the velocity before entering the target. The second

set determined the velocity after passing through the target. A missile trap (36x36x52 in), constructed of heavy armor plate steel sides and back, with a 3/4-in plywood front, and filled with sand, was located approximately 3 m from the second screen set.

All range distances were measured, including the target thickness, prior to firing, and entry and exit velocities were calculated for each firing. The ballistic screen sets were of the light beam type. As the missile passed through the first beam of a set, a timer was electronically started, and as the missile went through the second beam, the timer was stopped. This gave the time the sphere traveled 1 m as the beams were 1 m apart.

Barrel sighting and aligning of the target were accomplished by using a 2.4 mw laser beam directed down the barrel onto the target. By utilizing the laser beam, the barrel or the target was moved to give the desired point of impact.

Thigh muscles were fired upon in three general velocity groups, i.e., 500, 1000, and 1300 m/sec. Each rear leg was shot, one at a time, at the same general velocity, while the animal was still alive and anesthetized. After shooting, the animal was euthanatized and both legs were immediately removed and perfused with a tissue fixative (phosphate buffered neutral 10% formalin). Perfusion was at a constant pressure of 80 mm of mercury and the flow rate afforded by 1/8-in inside diameter plastic tubing with 14-gauge metal catheters attached to the ends of a t-tube and placed in the right and left iliac arteries. Fixation by perfusion was monitored for 2-3 hr until the muscle tissue was hard to the touch. At this time the wound tracts were removed from the legs with as much surrounding tissue as necessary to ascertain the extent of the circumferential damage in the tissues. The specimens were then placed in 5-gal stone containers with the same tissue fixative, and allowed to remain for a minimum of 1 wk to assure good infiltration of the fixative. At the end of the fixation time, the tissue was cut for approximate tract measurements (fixation causes shrinkage of tissues) and histologic examination. The cross section diameter of the permanent wound tracts was measured at 1 cm intervals from point of entry to point of exit. Tissue samples for histopathologic examination were collected each centimeter down the tract from dorsal, ventral,

medial and lateral radii, extending to 10 cm from the edge of a permanent tract when possible. Each sample was identified and processed with standard histologic techniques for paraffin embedding. Six micron sections were mounted on plain glass slides and stained with Harris' hematoxylin and eosin stain.

Immediately following euthanasia of the pig, the liver was removed intact and placed in a plastic bag (polyethylene, 0.005 in thick). This bag was suspended by three points to insure stability and prevent rotation. The thickest point on the bag was selected as the target and was measured for tract length. Using the same scheme as depicted for muscle, the livers were fired upon at several velocities (413-1129 m/sec). Following the shot, entrance and exit wounds were measured, the gross physical characteristics of the damaged organ were noted, and samples were taken for histologic examination.

RESULTS

500 meters per second - muscle and skin

Sixteen wounds in this velocity group (range 429-533 m/sec) were obtained (Table I). The wound tracts were through the thigh muscles and averaged 10.97 cm long from lateral skin entrance to medial skin exit.

The wounds of entry and exit created by the sphere in the skin were 0.60-0.75 cm in diameter. The point of exit was self-closing and, except for hemorrhage, was difficult to find. The margin of the entrance wound was clean-cut, such as one might see with a cutaneous biopsy punch. Histologically, the entrance and exit wounds were very similar. The epidermis was clean-cut with the cornified layer sometimes slightly extending over the opening. The dermal collagenous fibers, blood vessels, nerves, lymphatics, and glands were grossly torn apart on the immediate edge of the permanent tract; however, individual cellular detail as seen with the light microscope appeared normal. Fat cells in the subcutaneous tissue adjacent to the wound tract appeared normal.

The permanent wound tracts through the muscles and related fascia were, in all test subjects, less than 1 cm in diameter and were occluded with bits of macerated tissue and blood clots. Ruptured or broken muscle fibers were confined to 1 cm from the permanent wound tract margin.

TABLE I. FIVE HUNDRED METERS PER SECOND VELOCITY GROUP

Striking velocity (m/sec)	Exit velocity (m/sec)	Energy (Joules)			Wound tract length (cm)	Energy (Joules) loss/cm
		Striking	Exit	Energy loss		
429.254	142.866	95.520	10.581	84.939	14.0	6.06
533.410	243.480	147.498	30.732	116.766	13.0	8.98
475.111	185.128	117.018	17.766	99.251	11.1	8.94
491.965	210.053	125.468	22.873	102.595	10.3	9.96
503.212	228.508	131.270	27.068	104.202	10.3	10.11
439.385	163.603	100.287	13.875	86.411	11.1	7.78
523.478	209.645	142.057	22.784	119.272	12.8	9.31
461.701	234.079	110.506	28.404	82.101	10.4	7.89
456.987	251.371	108.261	32.756	75.505	9.8	7.70
439.345	199.688	100.063	20.671	79.392	9.6	8.27
492.380	261.557	125.680	35.464	90.215	9.1	9.91
485.059	234.250	121.970	28.446	93.524	10.3	9.08
449.905	182.798	104.932	17.322	87.609	10.3	8.50
522.643	246.584	141.604	31.520	110.083	9.7	11.34
453.677	210.907	106.699	23.059	83.639	9.8	8.53
513.988	199.496	136.953	20.631	116.321	14.0	8.30
Average:						
479.468	212.750	119.737	23.997	95.739	10.975	8.79

$$\text{Joules} = \frac{\frac{1}{2} m \cdot v^2}{10^7}$$

m in gm. v in cm/sec.

Ecchymotic hemorrhage was observed 1-2 cm from the permanent wound tract in all test subjects. Petechial hemorrhages occurred 3-10 cm from the permanent tract. Hemorrhage beyond the margin of the permanent tract was due to rupture of small blood vessels. No large vessels away from the margin of the permanent tract had apparent damage.

1000 meters per second - muscle and skin

In the 1000 m/sec velocity category, 17 wounds were created with impact velocity range of 936-1202 m/sec (Table II). The tracts through the thigh muscles averaged 13.5 cm in length from point of entry to point of exit. The entry wound diameter in the skin was 1-1.5 cm in this group. An occasional laceration of the skin radiating from the margin of the entrance wound occurred in the higher velocities of this group. The exit wound was smaller than the entry wound in all subjects of this group and measured 0.5-0.8 cm in diameter. This velocity caused considerable visible movement of the target in the form of oscillations. High speed photographs of the surface exhibited shock waves

extending from the missile's path through the tissues much as a rock dropped into water (Fig. 2, A and B).

The permanent wound tract diameter varied in size in a given wound and ranged from 1-2 cm. The permanent tracts were progressively wider as the entry velocity was increased within this group and often measured 2 cm in diameter at the upper levels. Ecchymotic hemorrhages were common 1-3 cm from the permanent tract and smaller focal hemorrhages were more prominent in numbers and distance than in the 500 m/sec velocity group.

Microscopically, ruptured capillaries were noted 1-3 cm from the permanent missile tract. Large arteries within 1 cm of the margin of the permanent missile tract had a disruption ("sunburst" effect) of the medial wall and adventitia, but the intimal layer was still intact (Fig. 3). Broken muscle fibers were seen within 1 cm from the margin of the permanent tract. Often only a few fibers in a given group would be ruptured or broken. A rounded eosinophilic globule (probably sarcoplasm) was noted in some of the broken fibers.

TABLE II. ONE THOUSAND METERS PER SECOND VELOCITY GROUP

Striking velocity (m/sec)	Exit velocity (m/sec)	Energy (Joules)			Wound tract length (cm)	Energy (Joules) loss/cm
		Striking	Exit	Energy loss		
1186.074	529.952	729.270	145.592	583.678	13.0	44.89
1173.793	522.928	714.247	141.758	572.488	16.0	35.78
1181.379	534.597	723.508	148.155	575.353	14.0	41.09
1177.300	547.949	718.521	155.648	562.872	12.8	43.97
1111.416	497.991	640.352	128.560	511.991	14.3	35.78
1040.534	468.162	561.277	113.620	447.656	13.6	32.91
1016.556	538.737	535.708	150.459	385.249	12.0	32.10
1037.464	454.727	557.970	107.193	450.777	14.3	31.52
1202.348	441.845	749.420	101.206	648.214	14.8	43.79
948.557	468.387	466.436	113.729	352.706	12.6	27.89
1023.011	458.397	542.533	108.930	433.602	13.6	31.88
1021.488	517.823	540.918	139.004	401.914	13.5	29.77
957.564	462.492	475.335	110.885	364.450	12.8	28.47
1130.338	524.191	662.341	142.444	519.896	13.3	39.08
951.276	426.393	469.114	94.251	374.863	13.6	27.56
936.724	453.470	454.871	106.601	348.270	13.2	26.38
936.879	453.913	455.072	106.809	348.212	13.0	26.78
Average:						
1060.478	488.350	588.064	124.403	463.676	13.55	34.96

$$\text{Joules} = \frac{\frac{1}{2} m \cdot v^2}{10^7}$$

m in gm. v in cm/sec.

1300 meters per second - muscle and skin

Fifteen thighs were wounded with velocity ranges of 1231-1427 m/sec (Table III). The pigs used in this group were somewhat larger than the other groups, with an average tract length of 16.04 cm through the posterior thigh muscle group.

The entry wound was often lacerated, making the overall circumference of the wound significantly larger. Discounting the laceration, however, the diameters were 2-3 cm. The temporary skin wound diameter was considerably larger than seen photographically at lower velocities (Fig. 4, A and B). The subcutaneous fat had focal hemorrhages as far as 10 cm from the margin of the entry wound and 6 cm from the exit wound. The permanent missile tract in the muscle tissue was quite extensive and averaged about 2 cm with a range of 1-3 cm. The variation in diameters was due to the connective tissue of the fascial planes with the narrow dimensions of the permanent tracts in the fascial plane areas. Ecchymotic hemorrhage occurred 2-4 cm from the margin of the permanent tract. Petechial hemorrhages were found throughout the posterior

muscles of the leg but were most numerous within the first 6 cm from the margin of the permanent missile tract.

Microscopically, torn or ruptured capillaries were observed 4-6 cm from the margin of the permanent tract in the muscle. Broken muscle fibers were found within 1 cm in all sections and in some sections as far as 3 cm from the margin of the permanent tract. Large arteries within the first centimeter from the permanent tract had disrupted muscular walls and connective tissue adventitia and often had a ruptured or torn intima resulting in hemorrhage. Nerve trunks adjacent to the permanent tract had disrupted sheaths but no broken axons were seen in our sections.

Liver

The entry and exit wounds at velocities above 500 m/sec had tears or "rupture lines" in the tissue radiating out from the permanent tract (Fig. 5). These tears or "rupture lines" became more extensive as the velocity increased until at 938 m/sec and above the tissue was grossly disrupted in contrast to perforation at lower velocities.

TABLE III. THIRTEEN HUNDRED METERS PER SECOND VELOCITY GROUP

Striking velocity (m/sec)	Exit velocity (m/sec)	Energy (Joules)			Wound tract length (cm)	Energy (Joules) loss/cm
		Striking	Exit	Energy loss		
1231.952	572.353	786.779	169.822	616.957	13.0	47.45
1293.321	555.569	867.117	158.857	708.259	15.0	47.21
1320.610	704.102	904.095	257.001	647.093	10.5	61.62
1329.430	513.023	916.212	136.439	779.772	19.0	41.04
1346.874	346.988	940.414	62.415	877.998	16.0	54.87
1336.082	532.653	925.404	147.080	778.324	18.0	43.24
1337.463	552.230	927.317	158.090	769.227	18.0	42.73
1313.929	502.512	894.971	130.905	764.065	19.0	40.21
1331.644	523.499	919.266	142.068	777.198	21.0	37.00
1316.464	555.288	898.427	159.846	738.581	18.0	41.03
1333.720	465.155	922.134	112.165	809.969	20.0	40.49
1329.413	601.741	916.189	187.709	728.480	15.0	48.56
1261.134	585.035	824.494	177.430	647.063	12.7	50.94
1397.642	707.618	1012.644	259.575	753.068	14.0	53.79
1427.380	713.338	1056.196	263.788	792.407	11.5	68.90
Average:						
1327.137	561.940	913.777	168.213	745.897	16.05	47.94

$$\text{Joules} = \frac{\frac{1}{2} m \cdot v^2}{10^7}$$

m in gm.

v in cm/sec.

TABLE IV. LIVER WOUND DATA

Striking velocity (m/sec)	Exit velocity (m/sec)	Energy (Joules)			Wound tract length (cm)	Energy (Joules) loss (cm)
		Striking	Exit	Energy loss		
413.326	185.977	88.56	17.92	70.60	9.5	7.43
427.154	231.080	106.08	31.04	75.00	12.0	6.25
458.498	216.569	108.97	24.31	84.60	11.5	7.35
465.252	267.984	112.21	37.22	75.00	8.0	9.37
491.342	272.717	125.15	38.55	86.60	10.0	8.66
506.056	269.185	132.75	37.56	95.20	9.0	3.65
573.570	304.716	170.54	48.13	122.40	10.0	12.20
665.743	438.877	229.76	99.85	129.90	8.4	15.40
680.324	396.096	239.90	81.33	157.67	9.5	16.70
756.004	602.620	296.28	188.25	108.00	10.2	10.50
771.521	464.944	308.50	112.06	196.50	9.0	21.80
938.872	542.374	456.95	152.49	304.50	10.0	30.40
950.716	546.746	468.56	154.96	313.60	11.0	28.50
950.716	591.761	468.56	169.47	299.10	10.0	29.90
959.908	609.050	477.66	192.29	285.40	10.7	26.60
961.948	531.876	479.69	146.65	333.00	11.0	30.20
982.344	560.459	502.55	162.83	337.40	9.3	36.20
1045.030	836.930	566.13	363.11	203.00	10.4	19.50
1052.169	651.969	573.89	220.35	353.50	8.0	41.60
1129.893	672.117	661.81	234.18	427.70	10.0	42.70

Histologic examination of the liver tissues with the light microscope revealed disassociated cytologically normal hepatocytes within the first centimeter adjacent to the missile tract. Liver tissue energy extraction levels were determined (Table IV).

DISCUSSION

In the skin-muscle-skin study, a relationship was noted between striking velocity-kinetic energy and the extent of damage in the tissue. It can be seen from the data presented that entry wound size, permanent cone diameter, radius of broken fibers and radius of hemorrhage gradually increased with increase in missile velocity (Table V). Damage to liver tissue was also directly proportional to striking kinetic energy, as expected. Tearing of the tissue and permanent tract width both increased significantly with velocity increase.

Within the scope of this study, however, we were not able to delineate histologically the extent of the temporary cavity created by transit of the missile. Broken muscle fibers and petechial hemorrhage were the only remote lesions noted in the muscle study and these were in a somewhat random distribution. In the liver study, there were no significant remote lesions. It is highly

conceivable that the increased kinetic energy in the area of the temporary cavity would cause ultrastructural changes in the tissues that would result in loss of cell function and cell death at some protracted period following wounding. In that case, the light microscope is not capable of detecting these changes, and our study of acute effects would preclude discovery of latent events. This observation of microscopic evidence of muscle tissue damage is in agreement with that of Krauss⁹ who extended his studies of soft tissue wounding by use of high-speed radiography. By those methods he was able to deduce ratios of temporary to permanent cavity diameter for muscle and liver.

It was theorized that tissues are capable of absorbing a given quantity of energy which is specific for the type of tissue and energy loss per centimeter of tract length seems to be an acceptable parameter for comparison. In our study, liver and skin-muscle-skin wounds gave similar energy losses per cm at comparable striking velocities. This is compatible with the fact that the specific gravity of muscle (specific gravity = 1.02-1.04) and liver (specific gravity = 1.01-1.02) are approximately equal.¹⁰

TABLE V. SKIN-MUSCLE-SKIN WOUND SUMMARY

500 meters per second velocity group

Entry wound	0.6-0.75 cm
Permanent tract diameter	less than 1.0 cm
Broken fibers	1 cm from margin of permanent tract
Hemorrhage	Ecchymotic 2 cm from margin of permanent tract Petechial 10 cm from margin of permanent tract

1000 meters per second velocity group

Entry wound	1-1.5 cm
Permanent tract diameter	1-2 cm
Broken fibers	1 cm from margin of permanent tract
Hemorrhage	Ecchymotic 3 cm from margin of permanent tract Petechial more than 10 cm from margin of permanent tract

1300 meters per second velocity group

Entry wound	2-3 cm
Permanent tract diameter	3 cm
Broken fibers	3 cm from margin of permanent tract
Hemorrhage	Ecchymotic 4 cm from margin of permanent tract Petechial more than 10 cm from margin of permanent tract

We observed that at a striking velocity of 938 m/sec and above, the liver tissue lost gross anatomic integrity in the vicinity of the temporary cavity; in essence, it exploded. According to our data, that velocity was characterized by a striking energy of 456.95 Joules, and an energy loss in tissue of 305.50 Joules which could approximate an explosive threshold for liver tissue. Amato et al.¹⁰ noted that the cohesive structure of liver is less than that of muscle; therefore, when struck by a high velocity missile, liver cells are loosened from their supporting structures during undulation of the tissues of the temporary cavity area. The temporary cavity, in liver, therefore, is approximately equal in size to the permanent cavity.¹⁰

Muscle tissue is apparently capable of absorbing significantly greater quantities of energy than liver. Shots were fired with striking energies up to 1056 Joules (1427 m/sec velocity) with a tissue absorption of 792 Joules, without evidence of "explosive" effects of the thigh muscle at these levels or below. If a threshold effect for explosion exists for skin and muscle, then we obviously have not reached it with this series of shots.

The fact of exit wounds being smaller than entrance wounds, contrary to what is ordinarily seen in bullet wounds, is probably explained by the use of a sphere as the projectile. With use of non-spherical missiles, any tumbling results in larger presented areas, while with spheres, the presented area is uniform regardless of projectile behavior.

CONCLUSION

Permanent missile tracts in liver and muscle tissues increase in diameter as the impact velocity is increased. Remote tissue damage is related to the physical characteristics of the tissue involved as well as the impact velocity.

Energy absorption per centimeter of wound tract length is approximately the same for liver and skin-muscle-skin. Liver tissue in the vicinity of the wound tract is greatly disrupted at energy absorption above 300 Joules (striking velocity of 938 m/sec); whereas, lower energy levels (lower velocities) results in simple perforation of liver. In muscle exposed to striking velocities up to 1427 m/sec and energy absorption of 792 Joules, no such gross disruptive effects occur.

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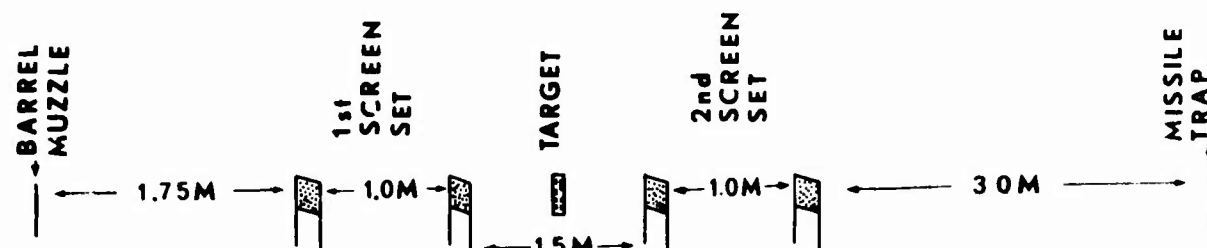


Fig. 1. Ballistics range plan.

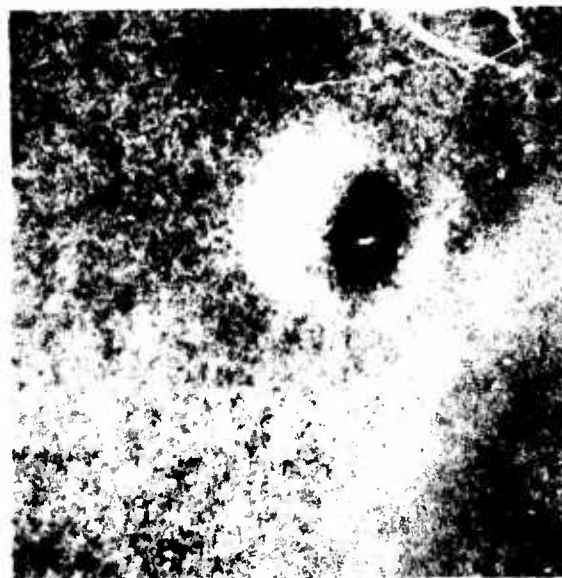


Fig. 2A. Point of impact of sphere with a velocity of 936 m/sec on skin over muscle.

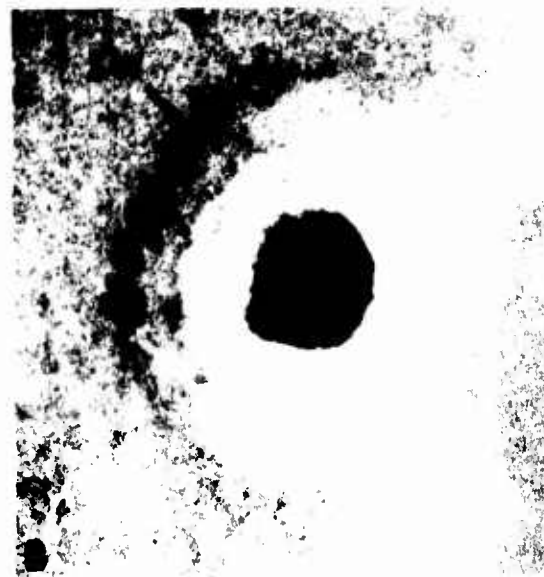


Fig. 2B. Entry wound in skin over muscle 0.133 millisecond after Fig. 2A. Note the shock wave radiating from the opening in the tissues (SW).

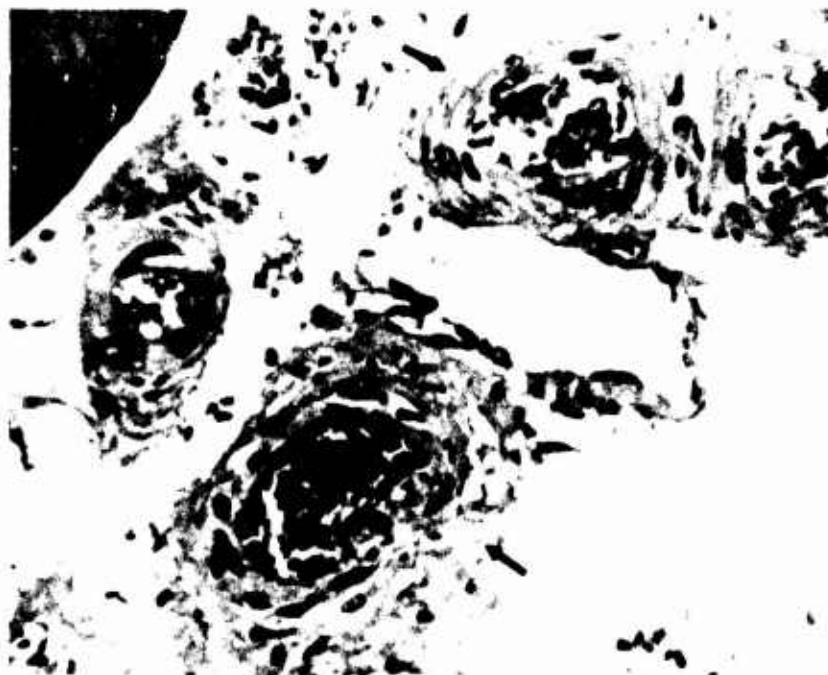


Fig. 3. Cross section of small arteries with disassociated adventitia and media (arrows). Hematoxylin and eosin stain. 400X.



Fig. 4A. Point of impact of sphere with a velocity of 1427 m/sec on skin over muscle.

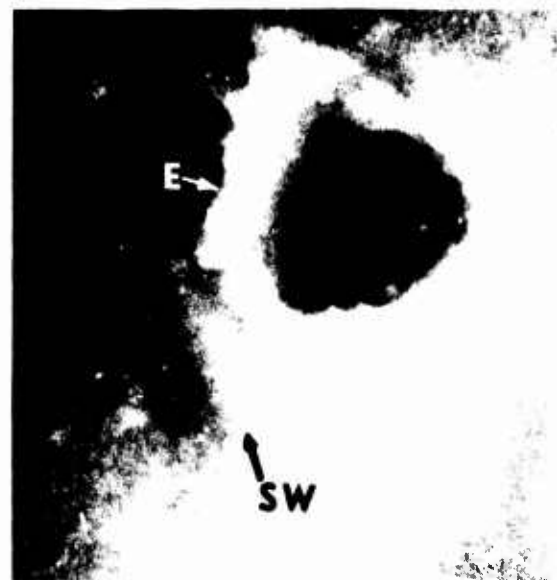


Fig. 4B. Entry wound in skin over muscle 0.150 millisecond after Fig. 4A. Note the "explosive" effect with eversion of the entry wound margin (E) and shock wave (SW).



Fig. 5. Liver with permanent tract (PT) and radiating tears or rupture lines (arrows). The wound was created by sphere with 537.5 m/sec impact velocity.