EXPERIMENT AND EXPERIENCE WITH THE RIFLE

8.

BY

HENRY G. BEYER, M.D.

U. S. NAVY

Reprinted from the Boston Medical and Surgical Journal of January 3, 1901

BOSTON
DAMRELL & UPHAM, PUBLISHERS
No. 283 Washington Street
1901

S. J. PARKHILL & CO., BOSTON, U.S.A.
PRINTERS

EXPERIMENT AND EXPERIENCE WITH THE RIFLE.[1]

BY HENRY G. BEYER, M.D., U. S. NAVY.

In these uncertain and turbulent times when the peace balance of foreign relations has reached so high a degree of sensitiveness as to be disturbed and upset by a breath; when war clouds start up most unexpectedly and from the most unlooked-for quarters of the globe, and chase each other in rapid succession, the study of military surgery claims a much larger share of the attention of the medical student than ever before. Within the last two years a very considerable amount of knowledge has been harvested on the field of battle, and presented to us in the shape of some of the most excellent monographs ever written on the subject. Every student of military surgery, taking his profession seriously, and, therefore, seeking every available opportunity to inform himself and keep abreast with the times, must feel a debt of gratitude for the very instructive reports that have come to him and the profession from Senn, Nancrede, La Garde, Borden, Sir William MacCormac, Treves, Dent, and many others.

There has, perhaps, never been a time in the whole history of field operations when any one particular weapon has wielded so powerful an influence on both

[1] Read before the Boston Society for Medical Improvement, November 26, 1900.

friend and foe, professional soldier as well as a layman, and on the military medical man, as has the present infantry rifle. The influence of the practical work of this gun in the field upon both offensive and defensive operations, upon the disciplined courage of the soldiers, upon future drills and upon the handling of the wounded, both during and after the battle, has, perhaps, not yet been fully measured and realized. Enough, however, has already been done and accomplished to bring us to a full sense of realization of the great and overwhelming importance of the present infantry rifle.

When we consider that, at the battle of Colenso, in the Anglo-Boer War, 97.5% of all the wounds were due to rifle fire, and only 2.5% to shell fire, an intimate study and acquaintance of the work done by this phenomenal piece of machinery, on the part of the surgeon, ought to need no further argument. In order that the conclusions which have been reached and formulated shall prove enduring and useful in the future, it would seem both desirable as well as necessary for us to carefully weigh and measure the evidence that has so far accumulated on both the experimental and practical side of the question. Before going into the details of either side, let us once for all keep in mind the more general as well as significant fact, also the result of recent experience in the field, that the proportion of the killed to the wounded, a proportion of 1 : 4, remains nearly the same as in former wars, although the percentage number of recoveries from among the wounded has been largely increased under the new bullet. There seems to be, moreover, little doubt on the part of the most experienced military surgeons that, after all shall have been said and sifted with regard to the humane character of the new bullet, and after due and proper allowance shall have been made for the influence of antiseptic methods of surgery, the palm of humanity will be found to belong as much to Lister, the man who originated antisepsis in 1876, as to Reger, the man who introduced the steel-jacketed bullet in 1884. With regard to this point Dr. Borden says ("Gunshot Wounds"): "I venture to say that had modern methods of asepsis and antisepsis been in use during our Civil War, the results would have been so different from those actually obtained, that it would have been seen that it was the surgical method employed, and not the particular bullet, which most influenced the result. . . . It was probing with dirty probes and unclean fingers, and unnecessary operative interference under septic conditions and septic dressings, that was responsible for unfavorable results and high mortality."

With these general facts in mind, let us first turn our attention to the side of the experimenter.

A close and careful study of that most excellent monograph by Kocher, "Zur Lehre von den Schusswunden," Cassel, 1895, cannot help but result in showing that almost every injury produced by the new bullet that has been described so far as having occurred in the field has its prototype among the experimental results recorded in that work and the rest will find a most satisfactory explanation. The conscientious, unbiased and discriminating student, looking for the grand principles underlying the production of gunshot wounds, and not for the minor and non-essential details that were merely deduced, will find himself richly rewarded by a perusal of this work.

Let us, therefore, spend a short time in turning our attention to the contents of this monograph and the splendid illustrations that accompany the same. From it we learn that Kocher has experimented annually for a period of nearly twenty years, and his chief merit consists in that he has furnished the best explanation of the nature and the manner of production of what is known as *explosive effect.* From my own limited experience with experimental injuries, I may be permitted to say right here that, when once the peculiar conditions under which this explosive effect is produced are thoroughly known and correctly appreciated by the student of military surgery, the whole subject of gunshot injuries and their production under the most varied conditions, on either the living or the dead, in the field or in the laboratory, becomes unexpectedly clear.

Explosive effect in general has been attributed by different observers to a variety of causes and conditions, namely: (1) To deformed and deforming bullets; (2) to direct or ricochet shots; (3) to the rotation of bullets; (4) the melting of the lead of the bullet.

Kocher, while willingly admitting, and, thereby, basing himself on his own experiments, that any and all the above-named conditions may co-operate in its production, sees in none of them the principal and primary cause of the explosive effect, inasmuch as he has produced the effect by underformed, non-rotating and non-melting bullets, providing he gave these bullets the required velocity. According to Kocher, moreover, explosive effect, whether occurring in dry substances or in organs saturated with water, is due to and may be explained by the operation of the same physical law.

As early as 1880, now twenty years ago, Kocher had demanded that it should be made a matter of international law and agreement to introduce metals in the manufacture of projectiles that possessed a higher melting point, greater hardness and a smaller diameter than the ordinary leaden bullets used at that time.

He had already, then, convinced himself by experiment and observation that every increase in the frontage or the cross area of the attacking surface of a projectile was followed by diminished penetration and an increased explosive effect. It made no difference whether this surface was peculiar to the size of an original bullet or whether it was secondarily produced by deformity of a smaller bullet, owing to greater velocity being given to it than it could bear without becoming deformed.

Kocher, therefore, demanded that every further increase in the velocity given to any bullet should at once be compensated for by giving it a correspondingly increased hardness, because that alone could prevent the conversion of a small calibre projectile into one of large calibre by deformity on impact.

It was upon principles such as these that the early experimenters worked and succeeded in counteracting and correcting the disadvantages to mankind growing out of the higher velocities given to bullets for merely technical reasons; and so successfully did they struggle and do their unselfish work that today, it may be said, it is chiefly owing to these humane efforts on the part of experimenters that explosive effects for the human body have been practically eliminated from every part of it, except the very hardest portions of bone and those organs that contain a large percentage amount of fluids in their composition. That this is true, recent experience in war has so fully demonstrated as to produce almost the impression of disappointment upon the surgeons, not acquainted with either the views or the results of experimenters. Whence, otherwise, the seeming embarrassment on the part of some surgeons with regard to the lodgment of bullets; for instance, that low velocity bullets, no matter what their calibre, must arrive at a point where they will no longer penetrate is in perfect accordance with and not "despite all theory and experiment" (Nancrede). If none of that "appalling destructiveness" attributed to the new projectile, which experiment, made on the dead body and on animals, appeared to forecast, was seen, it was simply a matter of range or the low velocities by which the particular injuries referred to were produced.

The question as to whether the interest of the individual has overridden that of the State, by the reduction of the calibre of the bullet, or whether it has not, does not so much interest the surgeon as it does the professional soldier; it is enough for us to bear in mind that it was one of the aims of experimenters to produce a bullet that should be less destructive on the human body than the old leaden bullet. That this has been actually accomplished, recent experience has confirmed.

In order to make accurate comparisons between the effects produced by bullets of different dimensions and compositions, at varying distances from the muzzle, it became very desirable, soon after systematic experiments were begun, to have the objects of experiment near enough for accurate aiming and still strike that object with a velocity which should exactly correspond to that which the bullet would develop at any desired distance from the muzzle. The curve which a bullet describes from the time it leaves the gun to the moment when it falls to the ground is known as its trajectory. A bullet develops its greatest velocity a few feet from the muzzle of the gun. From that moment it steadily decreases until the bullet strikes the ground. The velocities which bullets develop at different distances have been ascertained for most of them and are, therefore known. (Tables A and B.)

TABLE A.

Decrease in velocity by distance. Projectiles 10 millimetres.

Velocity			Losses in metres.
Velocity	at muzzle	= 435 metres.	
"	25 metres from "	= 410 "	25
"	50 " " "	= 390 "	45
"	100 " " "	= 352 "	83
"	150 " " "	= 327 "	108
"	200 " " "	= 308 "	127
"	400 " " "	= 262 "	173
"	600 " " "	= 232 "	203
"	800 " " "	= 208 "	227
"	1,000 " " "	= 187 "	248

TABLE B.

Decrease in velocity by distance. Projectiles 7.5 millimetres.

Distance.	Velocity.	Decrease. in metres.
0 metres.	600 metres.	
25 "	581 "	19
50 "	563 "	37
100 "	532 "	68
150 "	504 "	96
200 "	478 "	122
300 "	434 "	166
400 "	398 "	202
600 "	341 "	259
800 "	298 "	302
1,000 "	264 "	336
1,500 "	207 "	393
2,000 "	170 "	430

By reducing the amount of our ammunition we may give any bullet such a velocity close to the muzzle as will accurately correspond to that which a full ammunition bullet would develop at any desired distance from the muzzle. Heppner and Garfinkel were the first to make experiments with such charges of reduced ammunition and Kocher finds that the alleged differences in the injuries produced, as compared to those at real distances, are so slight and uncertain that they might easily be explained on other grounds.

Kocher's experiments are so numerous and cover such an immense ground in time, scope, skill and material; they were done under conditions so varied, that it would seem as if the field had been thoroughly and absolutely exhausted. The velocities with which he experimented varied from 25 m. to 800 m. The calibre of his bullets varied from 5.8 mm. to 16 mm.

in diameter. The different projectiles varied in weight from 1.9 gr. to 23.6 gr. Both their volume and specific gravity were taken into account. The hardness of his bullets varied from steel to wax; he used rifles as well as smooth-bore guns. Lastly, the greatest variety of material was used to serve in the place of targets.

Glass plates. — Glass plates represent the brittle tissues and much useful knowledge has been derived from shooting through these with different velocities and projectiles. Kocher's plates had a thickness of 3 mm. and were 30 $cm.^2$ and encased in a wooden frame being suspended from above.

Firing at such plates with a bullet moving at the rate of 25 m. per second we obtain a defect in them, consisting in an irregular hole, larger than the diameter of the bullet and, radiating from this irregular opening, we notice several long and straight fissures, reaching the periphery of the plate. Bullets with a velocity from 250 to 400 m. show that the effect produced in the plate becomes more concentrated towards the point struck. The fissures are finer, more numerous and shorter, *not* extending to the periphery of the plate. With velocities varying from 400 to 600 m., we obtain still more intensified central defects. Instead of a large irregular opening, the defect is a small round hol· approaching in diameter that of the bullets; the short and straight cracks radiating from the hole are very fine and numerous; at some distance from the central defect are seen circular, branching, intercommunicating cracks; all the cracks seem filled with powdered glass.

These effects, produced by bullets moving with different velocities, occur so regularly that the velocity share in the vital force of a bullet is shown to be by far the most important factor in their production. A

10 mm. lead bullet and a 7.5 mm steel bullet, moving alike with a velocity of 595 m., produce like effects. It is interesting to note that the plates themselves, when shot at with these enormous velocities, scarcely move at all.

Tin cans filled with marbles. — In solid and, more especially, the brittle class of bodies, the cohesion among the small particles to be overcome requires a greater force than is the case with fluids, but when their equilibrium has once been disturbed, it remains disturbed, while in the case of fluids the injury is quickly repaired. In order, nevertheless, to illustrate his conception of the perfect analogy existing between explosive effect in fluids by certain velocities, Kocher experimented with tin cans filled with marbles, in which, as will be readily seen, the solid particles were given a greater play of mobility upon each other than they had, for instance, in a solid block of stone.

Experiments with such cans show that velocities up to 250 m. are attended by effects marked principally in the line of flight of the bullet. Both entrance and exit openings are nearly alike in shape and extent. With increasing velocities, the lateral or explosive effects are beautifully brought out by the appearance of small humps on the surface of the cans; these are, first, noted about the exit, next, on the sides and, at last, with the highest velocities, in all directions. An exactly similar process occurs in water or in organs saturated with it under the same conditions. That small particles of melted lead from soft metal bullets have nothing whatever to do with the production of this effect, nor that their rotation affects these results very materially is proven by the circumstance that hard bullets fired from smooth-bore guns produce identical effects, providing they possessed the required velocity. The gall-stone-like flattenings on the marbles show the pressure exerted by one upon the other within the can.[2]

Sandstone blocks. — These were 9.6 cm. thick and 30 cm. square. On account of the great firmness of these plates, all the shots show a quicker exhaustion of both the penetrating and lateral or explosive force of the bullets used. Here the specific gravity of the bullet shows the value of its share in the vital energy. Lead has a more powerful effect than copper; copper a more powerful one than hollow tin filled with wood. Some of the plates are not perforated, but they show that a large, irregularly round plate of stone in the rear has been broken off. This injury being much larger than that in front of the plate, it shows the possibility of the transmission, in a funnel-shaped direction towards the exit, of the force of a bullet, without breaking the continuity of the object hit.

Iron plates. — These were 1 cm. in thickness. The experiments on iron plates serve the double purpose of showing the effects of the bullets on the plates and the reciprocal effects of the plates on the bullets under different conditions. Leaden bullets, for example, when fired into water, soap or wood, show as yet no deformity with velocities of 75 to 150 m. When sent against iron plates, at the same rate of speed, they experience considerable deformity. None of the bullets produces an impression up to 200 m. velocity. With a velocity of 435 m., a lead bullet produces an impression and leaves a whitish, star-shaped deposit, extending for several cm. around it. The bullet itself is mashed into a cake of 5 cm. in diameter, its posterior end alone having preserved

[2] See the Journal of the Boston Society of Medical Sciences, January, 1899.

its shape, being seen in the centre of the cake. An aluminium bullet, with the same velocity, produces no impression, leaving only a whitish deposit. These shots, then, would illustrate the dependence of the penetrative power of bullets upon the specific gravity of the latter, for, in spite of the velocity being the same, lead and copper will produce deep impressions, while the lighter aluminium only leaves a whitish deposit with a very shallow mark. That, however, the velocity also has a large share in the penetrating power is shown in the difference of the effects on iron plates produced by velocities of 200 m. and 435 m.

In substances like iron, therefore, in which the explosive effect does not occur, the penetrative power of a bullet is shown to be directly proportional to the two component parts of its vital energy ($m.v^2$) and inversely proportional to its volume. Anything, moreover, which diminishes the consistency of a bullet will also diminish its penetrating power.

Lead plates are 3.5 cm. thick and 30 cm. square. A 10 mm. lead bullet, sent against such a plate with a striking velocity of 435 m., gives rise to a cup-shaped depression, 3 cm. wide and 3.3 cm. deep, with a rim thrown up around the entrance, 2.5 cm. high and indented star fashion. A copper bullet of the same velocity completely penetrates the plate, entrance opening 2.2 cm. wide, exit opening 1.3 cm. wide; front rim 13 mm., rear rim 4 mm. high. A tin bullet with wooden filling of the same velocity as the preceding produces a depression 2.2 cm. wide, 2 cm. deep, with a rim 3 mm. high. The projectile is seen at the bottom of the cup-shaped depression, with the wooden filling partly forced out by a core of lead from plate entering in front. An aluminium bullet, same velocity, gives rise to a round impression, 2 cm. wide, 12 mm. deep, rim 1.5 mm. high.

Both soft and hard lead bullets, as well as steel- and copper-jacketed bullets, remain in the target with velocities of 150 m., producing, at the same time, hardly any lateral effect. With velocities of 400 m., those with steel jackets penetrate, and the rest nearly but not quite; while with velocities of 500 m., every bullet perforates the plate.

These shots on lead plates would, therefore, serve to show very clearly that the penetrative power of a bullet is primarily dependent on its velocity, next upon its specific gravity and, thirdly, upon its hardness or consistency. The same may be said of the amount of lateral or explosive effect, for it is seen that the diameter of the various openings in the plates is, in every instance, greater the greater the velocity. Notwithstanding, therefore, the undoubted influence of the calibre, the specific gravity and the consistency as well as the rotation of the bullet, its velocity dominates in the production of the characters of the resul ing injury.

By the earlier experimenters it was held that lateral or explosive effect could not be produced by a non-deformable bullet with any velocity. The funnel-shaped injury produced by these bullets, now known to be the second degree of explosive action, and in which the exit is wider than the entrance, was explained by them as being due to the rotation of the bullet. It was assumed that melted particles of lead from the projectile, together with parts of the target, were thrown into a whirl by the rotating bullet, these particles acting as secondary missiles and transmitting their energy in an ever-extending circle to the parts directly in front of them, and, in this manner, giving rise to the funnel-shaped defect. This explanation, no matter how alluring it may seem, became untenable after Kocher had produced this identical defect with hard, non-melting and non-deformable bullets, fired from smooth-bore guns.

Kocher's explanation of the nature and production of the lateral or explosive effect is, that the energy of the bullet is transmitted from the parts struck, first, in the direction of the line of fire; next, with increasing velocities, in a funnel-shaped direction towards the exit, and, lastly, with still greater and the greatest velocities, in all directions.

The lead plates, especially, show this effect so well, and prove the correctness of Kocher's explanation, because the action of the bullets on them is preserved in the form of a cast. Our own experiments on glass plates, lead plates, and tin cans filled with marbles have fully confirmed Kocher's views.

Soap plates. — These were 10 cm. thick, 60 cm.^{2}, and consisted of the common rosin soap. Bullets with velocities of 150 m. produced effects corresponding to the diameter of the projectiles used; with velocities of 300 m., funnel-shaped canals, 1 cm. in diameter, were produced; with velocities of 435 m., the canals became 2 cm. wide; with 600 m., the openings show a width of 4 cm., and deformable bullets with 600 m. velocity give openings of 9 cm. in diameter.

In these plates, therefore, the gradual increase in lateral effect with increasing velocities is well shown. Up to velocities of 250 m., soft lead bullets remain as yet undeformed; with velocities of 435 m., they lose one-half their length. Hard lead bullets lose one-fourth their length with 435 m. and with 595 m. of velocity, the very posterior end alone remains in shape.

The plates show, among other things, that the resistance offered by the target, no matter what may be its composition, increases as does the velocity of the bullet. When compared with the lead plates, the soap blocks show more delicate shades of difference as regards both the effects of different velocities as well as of the varying specific gravity of the projectiles used.

Tin vessels filled with water or substance saturated with it. — Bullets fired into tin cans that are filled with d y cotton, dry meat or sawdust give, with all velocities, entrances corresponding in shape and diameter to those of the bullet and exits about twice that size. When these substances are wet or the meat is fresh and succulent. then the exits become from four to five times larger than the entrances. With the highest velocities, the cans are torn open and fissured around the entrances.

With velocities from 410 m. or upwards all the vessels filled with water are rent apart and this hydraulic or hydrodynamic effect is made apparent whether these vessels are open or closed at the top. It is, therefore, not necessary, for the production of hydraulic effect, that the water be enclosed within rigid and unyielding walls. It is simply and most strikingly evident that the effect is due principally to the suddenness of the entrance of the bullet which leaves the water no time for making its escape in any direction, not even that of least resistance, but which tends to force it in all directions, like an explosion. It would seem as if the explosive energy of the ammunition that sent the bullet into the centre of the can had been translated into the can and suddenly transmitted to the water contained in it. Round bullets, fired from smooth-bore guns, produce identical effects with the same velocities as do rifle bullets.

Experiments with a water box. — In order to still further illustrate the hydraulic action of bullets in some organs of the human body, Kocher experimented with a water box. As regards hydraulic action, Busch was the first to suggest the idea that some of the effects produced by projectiles in some tissues or organs of the human body might possibly be explained on principles of hydraulic pressure. After him, Küster, Heppner and Garfinkel confirmed this idea and Kocher raised this hydraulic pressure theory to the dignity and importance of a law, true for all tissues of the body containing fluids. Later on, Reger, Bruns and Kikuzi did much to confirm and extend the experiments of the earlier authors.

Kocher had a box made, 345 cm. long, 56 cm. broad, 61 cm. high, open at the top and filled with water to a height from the bottom of 55 cm. Through the side of one end a hole was cut and this was covered in by leather of the kind used in making drumheads. This was kept in position by an iron frame fitting the opening, and through it the bullets were fired into the water in the box with varying velocities.

Three important results were brought out from these experiments, namely: (1) The dependence of the penetrating power of any bullet upon its velocity; (2) upon its specific gravity; (3) upon its form and deformability. I will here only cite a few examples: A copper bullet, 410 m. velocity, 34 cm. beneath the surface, advanced 256 cm.; a soft lead bullet, 410 m. velocity, 32 cm. beneath the surface, advanced 110 cm.; a hard lead bullet, 410 m. velocity, 33 cm. beneath the surface, advanced 285 cm.; a soft lead bullet, 250 m. velocity, 29 cm. beneath the surface, advanced 230 cm. under water.

It will be seen, therefore, with leaden bullets, that the amount of penetration is not directly proportional to the velocity, as is the case with hard and non-deformable bullets. Lead occupies an exceptional position in that it shows greater penetration with lower than it does with higher velocities.

When, moreover, leaden bullets are given velocities above 250 m. they will undergo deformity; a lead bullet, 25 mm. long, when sent into the water box with a velocity of 250 m. remains undeformed, while a velocity of 410 m. will cause it to become shortened to 14 mm. Knowing that the penetrating power of a projectile is inversely proportional to its cross-sectional area, it is almost certainly proven that the lessened penetration, noted above, is entirely due to the deformity which lead bullets undergo when striking the water in the box. That the deformity in this case is due to mechanical force and that, for instance, melting has nothing whatever to do with it, is proven by the facts (1) that mechanical force can produce the same degree of deformity, and (2) that metals with a much lower melting point than lead when fired into water with the same velocity remain solid.

A passing lead bullet evidently creates its own resistance in the water. The higher the velocity, the greater this resistance. From the moment the resistance reaches a point so as to cause deformity, which is at about the velocity of 250 m., explosive effect also becomes apparent. From that time on this effect is increased with the velocities used and at last it results in the bursting of the box and in the water spurting up to the height of 10 feet.

Based upon the results of these experiments and those on tin vessels filled with water, the conclusion seems unavoidable, namely: That the destructive effects of our modern high velocity bullets upon organs containing a large percentage amount of fluid are produced by hydraulic pressure.

That velocity has a preponderating influence upon the production of these effects was also shown by Salzmann (Kocher), who made use of bullets rolled out of filter paper in which "m," therefore, was as much as possible eliminated. With such bullets Salzmann obtained explosive effects in skulls and with the highest velocities, he was able to cause their complete destruction. The epiphyses of oxen at close range were completely exploded and, at 21 cm. from the muzzle, perforated. "Expansile effect" (Treves) does not seem a good subs'itute for the old time-honored name of "explosion."

Both Salzmann and Kocher agree in that the existence of an enclosing capsule is not a necessary condition for the production of explosive effect from hydraulic pressure and, while admitting that deformed and deformable bullets will increase the degree of the effect, the primary and principal cause of it is the velocity of a bullet. The principal reason why it has seemed so difficult at first to attribute to different causes the explosive effects in dry and wet substances is because the effects are not so much in evidence in fluids as they are in solids. The parts of a liquid after a moment come together again, while bone splinters, for instance, will remain splinters.

Measurement of explosive effect. — Nothing, certainly, could be better calculated to show the nature of explosive effect than the experiments of actual measurements by Kocher. Before, therefore, proceeding to study the effects of bullets on human tissues and organs, let us see what we can learn from the experiments made to measure the power of this all-important explosive effect. Two methods have been employed to this end. The one consists in direct manometrical measurement and the other in ascertaining the loss in velocity experienced by a bullet while penetrating its aim.

Table C (Kocher) shows loss of velocity in metres per second by a projectile after passing a 10 cm. layer of water enclosed within a pig's bladder.

TABLE C.

Projectile.	Calibre.	Original velocity.	Loss.
Hard lead . .	7.5 mm.	599 m.	190 m.
Copper jacket . .	7.5 "	595 "	57 "
Lorenz steel jacket	7.5 "	578 "	23 "
Hard lead . .	7.5 "	425 "	33 "
Copper jacket . .	7.5 "	425 "	30 "
Lorenz steel jacket	7.5 "	425 "	7 "
Hard lead . .	10.0 "	425 "	74 "
Soft lead . . .	10.0 "	425 "	117 "
Copper . . .	10.0 "	425 "	14 "
Copper . . .	round	425 "	64 "

The above table shows the enormous difference in the loss of velocity experienced by a large-calibre or a deformable small-calibre bullet, as compared to a small or non-deformable large-calibre bullet. It also shows the relatively greater loss of velocity with the higher than with the lower velocities for all bullets.

Table D (Kocher) shows the loss in velocity of a 10 mm. hard lead bullet after passing through the extremities of a human cadaver. Striking velocity = 420 m.

TABLE D.

Parts.	Loss in metres.
1. Upper arm	79
2. " "	60
3. Forearm	58
4. "	93
5. Thigh	139
6. Leg	183
7. Thigh muscles	124
8. " bone	175
9. Leg bones	123

The above experiments show that projectiles of different composition, and of which it has long since been known that they possessed different degrees of penetrative power, also experience different losses in velocity during their passage through certain aims. Generally speaking, this loss in velocity is inversely proportional to the hardness of the material of which the bullets are made and directly proportional to their calibre.

The Lorenz projectile, with its non-deformable steel jacket, loses the least amount in velocity, the Rubin projectile, with its strong copper jacket, comes next, and the hard lead projectile next, the soft lead last. By far the greater part of this loss in velocity is converted into lateral or explosive effect, because the loss in the total power of the bullet in becoming deformed is but a few kilogrammetres, amounting, as it does, in the case of a 10 mm. Vetterli, to only 6 or 7 kgm.

With a velocity of 410 m. a 10 mm. Vetterli strikes its aim with a force equal to 181.6 kgm. While penetrating the muscles of the thigh, it loses 92.6 kgm. or very nearly one-half of its original power, by a reduction of its velocity from 410 to 300 m In passing through the bones of the lower extremity, it loses 113 kgm., which greatly exceeds the amount of mechanical force necessary to cause its deformity, and which is only 10 kgm. It demonstrates the fact that the largest share of the original power of the bullet was converted into lateral or explosive effect, in this instance, at least twice as much as was necessary to cause its deformity and penetration together. From the fact that a bullet loses more of its force in passing through the lower than it does in passing through the upper extremity, we must, very naturally, expect the former to result in a more serious injury than the latter.

A knowledge of the losses in velocity of certain bullets through the different parts of the human body would enable the surgeon in the field to estimate the range of lodged bullets, providing the bullets did not happen to be badly deformed. We know, for example, that a 7.5 mm. bullet, with an initial velocity of 600 m., has a remaining velocity of 170 m. at 2,000 yards' distance from the muzzle. Supposing that it should, at that distance, enter the outer side of one thigh and go only through the fleshy part, thus losing 124 m. of this remaining 170 m.; supposing, further, that it now enters the other thigh in a direction towards the bone, with the remaining 46 m. of velocity, it would be bound to lodge in the femur of the second thigh. Such calculations would, in my opinion, come much nearer the actual range at which the fire was delivered than the best guess.

The second method of determining the amount of lateral effect consists in direct manometrical measurement. Reger was the first to employ this method, but Kocher, by devising a very ingenious piece of apparatus, obtained thereby much more accurate and reliable results than Reger. This is schematically represented in Fig. 1.

Legend. — Shows the lower part of a tin vessel filled with water. Into the bottom is fitted the cylindrical projection of the iron stand, within which slides a cylindrical piece of steel resting on a lead bullet. This may be fitted to the sides, top or bottom. When a shot is fired through the vessel the power exerted upon the water will cause the projectile to become shorter by direct compression. The mechanical power necessary to do this may be easily ascertained and expressed in kilogrammetres. By means of this piece of apparatus, Kocher was able to calculate the amount of lateral pressure caused by a 10 mm. Vetterli, 25 mm. long, entering a tin can filled with water and which amounted to a little over 23 kgm. per square centimetre of surface. By means of the same instrument, it was, moreover, clearly shown that hard lead bullets gave considerably less pressure than soft ones; more pressure was also produced when the projectile passed nearer to the measuring instrument than farther away from it, but regardless of whether the vessel itself was open or closed (see next table). While, therefore, the pressure may rise to a higher degree, when the water is enclosed within resisting walls, the effect itself occurs without such walls.

TABLE E (Kocher).

	Bullets.	Calibre.	Velocity.	Atmospheric pressure per cm.² Sides.	Bottom.
1.	Soft lead	10 mm.	435 m.	37.5	37
2.	Hard lead	7.5 "	595 "	42 5	41.5
3.	Copper jacket	7.5 "	595 "	20	22
4.	Lorenz steel jacket	7.5 "	595 "	21.5	24

Some experiments also were made with a hollow iron shot, into which holes were bored for the entrances and exits of bullets. These holes were closed with bladder skin and the shot filled with water, of which it held 1½ litres The result of shooting through it, under these conditions, was the bursting of the shell into fragments. Experiments with skulls, with the same apparatus attached, gave a lateral pressure of 10 atmospheres.

The analogy in the effects of bullets produced on tin cans containing water on the one hand, and on tin cans filled with marbles on the other hand. is that in both the water and the marbles are suddenly dispersed in all directions by the passing bullet when the latter has the required velocity. As the velocities increase from the lowest to the highest, we first notice only an effect in the direction of the shot, next by a funnel-shaped exit, and, at last, the effect shows itself in all directions, as is evidenced by the bursting of the can of water and the impressions of the marbles on the surface.

The very highest degree of this effect, and which presupposes the existence of rigid walls, is hydraulic pressure. But to this condition neither the skull, with its content of brain, nor the cylindical bones, with their marrow, exactly correspond. The hydrodynamic effect noted to occur in these is not the same in degree but only in kind.

Finally, since it is well known that water offers less resistance than does, for instance, the cortical substance of bone, we must expect that explosive effect in the latter will continue to occur with lower velocities and longer ranges than it does in water-containing tissues or organs. The effect itself, however, once produced, will reach a higher degree in water and water-containing tissues than it does in bones.

Human tissues and organs. — For the purpose of a better appreciation of the characters of gunshot injuries in the human body, we will do well to study such injuries on the different tissues separately. To this end, we may, with Kocher, divide them into three categories or classes: (1) The brittle; (2) those that contain fluids, and (3) the elastic tissues.

The brittle tissues. — The cortical substance of bone is the only tissue in the human body belonging to this class, and the more this preponderates over the other in any part, the more lateral effect in all its forms may be expected to occur in that part. The reduction in the calibre of bullets and the hard metallic jacket have resulted in reducing the size of skin wounds and limited the occurrence of hydraulic effect in the soft parts to shots at close range. The injuries to bones, on the other hand, continue to be serious. Special attention has been called by von Coler and Schjerning to the small skin wounds that are found over very serious bone injuries, particularly the long cylindrical bones. To one acquainted with experimental literature, it ought, therefore, give no surprise to find small skin wounds in the field even behind perforated bone. Nor would he allow himself to be misled by these small skin wounds as regards the possible existence of more serious injury to the bones underneath. That this has, however, actually occurred, we are led to infer from what Dent says with regard to these small wounds. He says: "A feature of small-bore wounds was the large amount of callus afterwards thrown out and, therefore, a neighboring joint might become fixed." The fissures existing in the bone underneath a small wound of exit are not so much in evidence in the field nor can they be brought out as clearly as a dissection on a cadaver can bring them to light in a laboratory. While, therefore, a surgeon not personally acquainted with experiments might be surprised at this abundance of callus which is thrown out, one who has such an acquaintance would, on the contrary, be led to look and prepare for such occurrences.

A careful comparison of the results obtained by experiment has, moreover, brought very prominently into notice slight differences in hardness, elasticity and percentage amount of moisture between different bones as well as different parts of the same bone. Hence, also, it has become clear that injuries produced under apparently identical conditions may still differ somewhat in character. Thus, for instance, the relative proportions of hard, bony substance to the volume of the cavities within have been studied and calculated by Habart and Friedrich (Kocher). In the femur of a young man the proportions of solid substance to volume were found to be 1 : 1.26 ; in the tibia, 1 : 1.6. In the femur of an old man the proportions were 1 : 2.11 and in the tibia 1 : 2.45. In a humerus, 32 cm. long, Habart found the marrow cavity 21 cm. long and 13 mm. at its greatest breadth. The closed spongy ends, measured 7 cm. above and 4 cm. below. The thickness of the cortical layer in the middle was

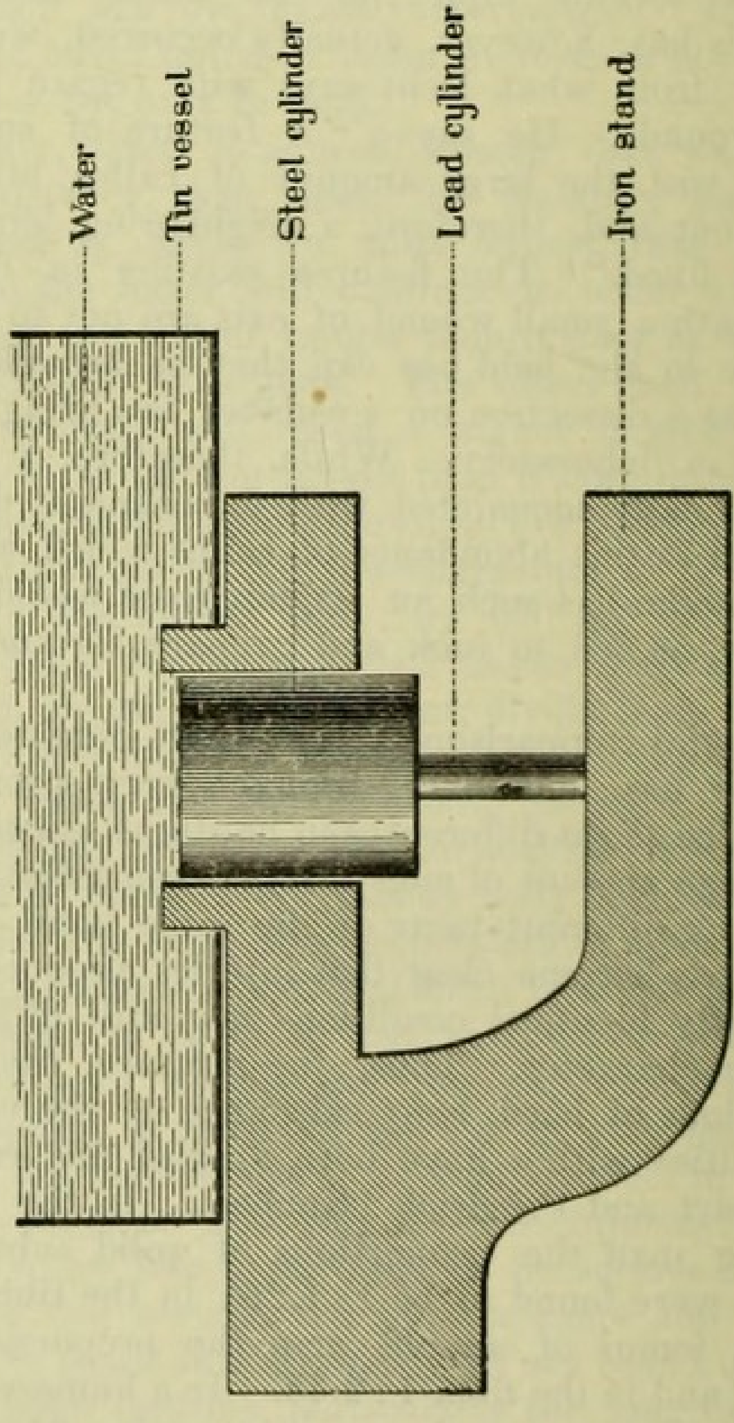

FIG. 2.

5 mm.; 4 cm. above the lower end it was 3 mm. thick, and where it passes over into the articular cartilage

it was only 1 mm. thick. The cortical layer of bone is, as a rule, slightly thicker in front than behind.

In view of the existence of these differences and the effect which these will exert on the production of injuries, it seems at once but reasonable to demand that they shall be taken into account whenever bone injuries either in the living or the dead are compared. Observing these points, Kocher, for instance, was unable to detect any differences between the injuries produced at long distances and such as were produced with reduced ammunition but by the same velocity at close range.

It is a well established fact that the lateral effect becomes greater the greater the resistance which a bullet has to overcome. As a solid body, therefore, bone must show signs of lateral effect with lower velocities, in other words, at greater distances than other tissues do. This same effect must, moreover, be greater the nearer we get to the middle of the diaphyses of cylindrical bones and to certain borders that are especially strengthened by extra layers of compact bone, such as we find about the linea aspera of the femur.

In view of the varying composition of different parts of the same bone, it is, moreover, easily understood how opinions could differ as widely as they did with regard to bone injuries in general. Since now, however, a distinction has been drawn between injuries to diaphyses, metaphyses and epiphyses, these differences of opinion have become reconciled.

The type of a gunshot fracture is today, as it was formerly, a fracture with splinters. Transverse and parallel longitudinal fractures are the result of bullets of low velocity in which the parts are simply pressed apart or bent and the walls pushed in. When, therefore, Mr. Treves says: "With regard to the alleged obliquity of fractures I should say deliberately that the great majority of fractures in this war due to Mauser bullets have been transverse,"[3] he gives the best possible and most unavoidable proof that the majority of fractures that came under his observation were produced at long range. The general rule is that the greater the distance or the lower the rate of velocity of a bullet producing a bone injury, the longer and the less numerous will be the splinters of the resulting fracture and the more likely it is that the splinters will remain in position and adherent to the periosteum; the bone may be perforated and yet show only long fissures running parallel to its long axis, as experiments have shown. The closer the range the smaller and the more numerous will the splinters be and the more perfect their separation from the periosteum as well as from each other. Fractures in which the splinters are small, fine and numerous and in which the exit is a large cavity filled with bone sand, driven into the neighboring and pulped muscles, may be produced experimentally at 100 m distance. That Mr. Treves[4] has seen some fractures that were produced at close range, we must infer when he says: "I have seen a fracture of the humerus in which the bone was broken into twenty-three small fragments,"[5] and, also, when he gives an account of a case in which the bullet had entered the epiphysis of the humerus and blown off its head, he says: "On examination, hardly any fragments of bone were found at all, they had been practically pulverized." This is a very lucid description of an explosive injury as it occurs in an epiphysis.

But even in such extensive bone injuries, it is not at

[3] British Medical Journal, May 19, 1900.

[4] Loc. cit.

[5] Loc. cit., January 27, 1900.

all uncommon to find both entrance and exit exceedingly small. In an experimental injury of this kind on a knee joint, I found both exit and entrance wounds small, not exceeding the diameter of the bullet, but dissection revealed complete comminution of the articular end of the tibia, the capsule of the joint filled to distention with bone sand. The copper jacket of the bullet was discovered in the centre of the mass of detritus ; the lead core, afterwards found on the floor, had alone escaped through the skin, causing a very small skin wound.

Between these two extremes we find the typical fracture first described by Bornhaupt and called by him a butterfly-fracture, occurring in long bones about the diaphysis. In this fracture. two triangular pieces of bone seem broken out on either side of the point of perforation. The apices of the triangles are at this point, while the hypothenuses are at the periphery of the bone. Behind is found a longitudinal fissure dividing the two fragments into two lateral halves. The evidence seems conclusive that the tubular character has everything to do with the production of this very characteristic fracture with certain velocities, because Bornhaupt has produced similar fractures in cylindrical glass tubes.

Mr. Treves,[6] speaking of bone injuries, says, " The following four statements are not borne out by experience in the present war. The first is that the severity of the injury to bone decreases as the range increases ; the second is that explosive effects are produced when a bone is hit at short range, such as 500 yards or under ; the third is that fractures are nearly always oblique, and the fourth is that when a bone is fractured, the exit wound is always larger than when this does not occur."

[6] British Medical Journal, January 27, 1900.

From what has already been said with regard to injuries to diaphyses and from what we shall hear presently with regard to injuries to epiphyses, the above cited four textbook statements do not perhaps go far enough to convey the full impression of their meaning, but as far as they do go they nevertheless appear to be not so far from being correct as Mr. Treves would have us believe.

Tissues containing fluids. (*a*) *Muscle.* — In muscular substance, explosive effect has reached its minimum degree of intensity. Bruns obtained clean perforative injuries at distances of 120 m. The canal was not larger than the diameter of the bullet and its adjoining walls were practically uninjured. Von Coler and Schjerning also obtained such injuries in near shots. That such injuries also have occurred in the field and at much larger distances, we must infer from what Sir William MacCormac says: "This slender, elongated bullet produces a canal not much, if anything, larger than a goose quill, and bores its way through, as if the hole had been done by a drill." Nevertheless, a defect in the muscles, in the direction of the bullet, attended by a total destruction of the parts to the extent of the diameter of the bullet, marks, according to Kocher, the first degree of explosive action.

At a distance of 30 m. explosive effect in muscle becomes very much more apparent. We obtained in a young ox an injury which involved both hind legs at that distance, about two minutes after he had been killed by a shot through the brain. The bullet entered the fleshy part of the left leg, midway between ankle and knee, and passed out through the right leg of the opposite side about the same point. The first entrance and the second exit wounds were not much larger than the calibre of the bullet, while the first exit and the second entrance wounds were of the size of a silver dollar. The wounds might be represented by two funnels, their wide ends turned towards each other, on the inside of the legs.

Shots through muscle, at greater distances than the above, result in canals that are smaller even than the calibre of the bullets, but the above example shows that hydrostatic pressure may be produced, even in muscle, by a simple increase in the velocity. It begins to show itself by a funnel-shaped exit and ends by a pulping of the tissue adjoining the track of the bullet. Mr. H. Temple Mursell,[7] civil surgeon attached to the British forces in South Africa, with regard to this point, says: "It has been frequently stated that the damage to the tissues inflicted by a small hard cased bullet, such as the Mauser, is comparatively small and, within certain limits, the statement appears to be correct. . . . In those instances in which it has been necessary from any cause to follow up the track of such a bullet wound. the death of the tissue around the track has been found to be much in excess of what might be anticipated. The resulting cylindrical cicatrix is of considerable extent and often produces more crippling than would be expected, owing to the muscles and their sheaths becoming firmly bound down." Such statements, based upon experience in the field and confirmatory of the experiments in the laboratory, might be multiplied. They would tend to make us slow and careful before pronouncing an opinion as to the benignity of an injury, because of the presence of small entrance and exit wounds. We must wait for more remote consequences. Many of those wounded in the war in Cuba, and whose wounds were considered trivial at the time, have since been invalided from the service.

[7] Lancet, January 23, 1900.

It has, moreover, been observed by Reger that, while in one muscle we obtain as yet clean perforations, in another, containing slightly more fluid, we already obtain a beginning explosive action, the velocity being the same in both cases. Muscles of different animals as well as different muscles from the same animal behave differently in this respect, and hence also the clash between the opinions of the earlier experimenters and of those in the field not thoroughly acquainted with these facts.

In the heart, liver, intestines and the bladder, the hydraulic effect begins to appear with velocities of about 250 m. and amounts to more or less, in accordance with the quantity of fluids which these tissues contain at the time, as experiments have abundantly shown. As regards the benign character of abdominal wounds oecurring in South Africa, Sir William MacCormac says, "I can only explain this considerable immunity by the frequently empty state of the intestinal tract at the time of the injury" (*Lancet*).

In the South-African War where, according to the reports, it happened not infrequently that both officers and men went without food or drink for ten and twelve consecutive hours through no fault of their own, all penetrating wounds would naturally be expected to be smaller, except those in the cortical portions of bone. This state of things was therefore not an unqualified evil, but rather a "blessing in disguise."

(*b*) *Spongy bone.* — In the diaphyses we have found an almost complete absence of hydraulic effect, which, in epiphyses and metaphyses, becomes the prominent feature. Hydraulic action commences to show itself in spongy portions of bone with velocities of 300 m. The spongy substance is ground up into sand, the cortical layer is splintered and these splinters are driven in all directions under the highest velocities.

Hence, also, the difference in the injuries between hard cortical and spongy epiphyseal bone and the necessity for a separate classification. It will, therefore, not do in the future to speak simply of bone injuries in *military* surgery, without specifying the parts of the bone in which these injuries were produced.

Busch (Kocher) has shown that the amount of destruction experienced by any part of a bone depends primarily upon the amount of resistance which it opposes to a bullet. This resistance is less in spongy than in hard bones. When, therefore, von Coler and Schjerning noted the occurrence of rather serious bone injuries at unusually great distances, while Reger and Bruns found them so slight as to call them benign and the bullets that produced them humane, the former experimenters referred to hard bone and the latter to injuries as they occurred in spongy bone.

(*c*) *Metaphyses.* — According to Kocher, it was first proposed in 1871 that the portion of bone lying midway between the epiphysis and the diaphysis of a long cylindrical bone should receive a separate name and its injuries treated under a separate head. The term "intermediary" bone was applied to it by German surgeons. Kocher proposed the name of "metaphysis," which seems to have been accepted. In this portion of bone, the cortical layers begin to become thinner than they are in the diaphyseal portion, while the spongy substance, at the same time, shows an increase. Hydraulic effect prevailing in the epiphyses, fractures with splinters about the diaphyses, injuries to metaphyses, must share the characters of either. Injuries to metaphyses are, as a rule, more serious than those of epiphyses and less so than those of diaphyses.

(*d*) *Flat bones.* — In flat bones, simple perforations seem to be the rule. Injuries to flat bones are serious only in direct proportion to the importance of the organs which they protect. The highest velocity shots upon skulls, filled with brain, show that they are attended by a high degree of explosive or hydraulic action. Any one having once fired a full velocity bullet at such a skull and seen the fragments of the skull fly apart, the brain scattered to the winds, will probably not again speak of "expansile effects," but will call the event a plain explosion. Empty skulls will give clean perforations and low velocities, irregular openings.

The elastic tissues. — Whenever we shoot into elastic material, such, for instance, as is represented by a soft, flexible rubber plate 3 cm. thick, we obtain a very uniform series of defects; mere conical perforations with the highest velocities and straight and very narrow canals with the lowest. The parts are shoved aside with such ease that a projectile of even the highest velocity at present attainable does not push the parts hit directly in front of it, but only shoves them aside temporarily. These uniform injuries cease to occur from the moment we substitute an inferior quality of rubber, so much so that the quality of rubber may be tested by a shot.

This circumstance has a practical bearing, for it is well known that by no means all the so-called elastic tissues of the body contain the same amount of elastic material, and in accordance with this difference, their injuries must differ just as do those of elastic rubber plates of different quality. Some elastic tissues, moreover, like the skin and the blood vessels, part much more easily in one direction than in another. Hence, we often get either transverse or longitudinal rents or fissures instead of clean perforations. In skin wounds on fresh cadavers, for instance, the elasticity of the skin becomes apparent only at the exit, because about the entrance it is backed by a less resilient tissue. Sometimes, also, but only with the lowest velocities, we obtain slit-like entrances which occur more often with the exits. With slightly higher velocities the entrance wounds become round. When, however, an elastic tissue is distended so as to neutralize its elastic nature in certain directions, we get perforative effects with loss of substance. This also occurs in situations where elastic tissue is adherent to non-elastic membranes.

Under such conditions the defect produced by a bullet in the skin, for instance, or the fascia, is of the form of that of the tissue directly underneath it: A round hole when over muscle; a longitudinal slit when over bone. When the injury has occurred in the neighborhood of tissues liable to show explosive effect, the skin partakes of the character of the injury done to those tissues. It is in this manner that we get the fissures and rents, shaped like an H or like a star, also the long tears in serous membranes and those covering the liver.

Nerves as well as blood vessels show sometimes a miraculous escape from injury even with the new bullet, but only with the lowest velocity; with the higher velocities, they are simply perforated and portions of their coats scooped out; the ordinary injury, however, is a transverse or longitudinal rent similar to that found in the skin.

Shots through lung tissue, especially when in a distended state, show a complete absence of lateral effect even with the very highest velocities, providing the bullet entered undeformed.

Experience in war. — We have seen from the preceding experimental evidence that the human body, from the point of view of the military surgeon, must be considered as a compound body, made up of a variety of tissues, each of which reacts differently upon a passing bullet. It is for these all-sufficient reasons that the original division of the trajectory of a bullet, with reference to the injuries to the human body, into three zones has been given up by experimenters years ago. Recent experience, also, would indicate that the injuries occuring in the field either are severe enough to cause immediate death, or promise a fair chance of recovery on account of their being rather light. Injuries in general, consequently, would naturally fall into two great groups, the severe and the light, and since the former occur at close range and the latter at long range, we now would more correctly speak of near-shots and far-shots (*Nahschüsse* and *Fernschüsse*).

Indeed, when we read carefully the descriptions given by military surgeons of the injuries which came under their treatment and observation in recent campaigns, we can hardly escape the conclusion that by far the greatest number of them were light. La Garde ("Remarks upon Gunshot Wounds") says that he only saw one case in Cuba that approached anything like explosive effects. This great scarcity of the severer class of injuries can only be due to the fact that engagements occurred at distances that made their occurrence impossible, while those that actually did occur were so severe that the men remained where they dropped and were buried out of sight long before the surgeons had time to notice them.

In any attempt, therefore, at discussing the injuries produced under the more exact conditions of experiment with those that occurred in the field, a comparison between the ranges would be of the first and greatest importance. It is here, also, that we meet with our first great difficulty, for it is easily seen, while the range in a shooting-gallery or laboratory can be measured with absolute accuracy, that in the field, in the majority of cases, must remain practically unknown. There is no guess, however good, no rangefinder, whatever its construction, that can approach an actual measurement of distance, or of the velocity of a bullet.

As regards South Africa, for instance, Mr. Charles A. Court, in the *Nineteenth Century* for November, 1900, page 712, says: "Until all ranks became accustomed to the clearness of the atmosphere, ranges were frequently underestimated by one-half the real distance. . . . The Boers, excellent shots, would open fire at 2,000 yards' range from every scrap of cover that could shelter a man."

Mr. Dent says with regard to range: "Unfortunately reliable information can very seldom be obtained on this point," and Mr. Treves [8] remarks: "The damage done by the Mauser depends mainly on the range." Although an additional four months' experience caused Mr. Treves to change his mind with regard to the influence of range, he has no doubt since then had sufficient leisure to repent and to revert to his former and more correct conclusion.

At any rate, those of us who have seen shots at close range, either due to accident or suicidal intent, and long distance injuries in the field must be pardoned for looking upon the range as having the most important bearing upon the character of the wounds produced by bullets. This is indeed so much the case that, even in the absence of more accurate information of field ranges, the trained military surgeon may be trusted to read the range in the character of the wound before him, with at least the same accuracy as any rangefinder can. We may, then, even without an exact knowledge of the field ranges at which bul-

[8] British Medical Journal, January 27, 1900.

let wounds are produced, conclude with perfect safety and all scientific reserve that practical experience has fully confirmed the results of experiments in respect to the influence of range. All other conclusions contrary to this would seem to have been arrived at without a knowledge or personal acquaintance with experimental injuries, so necessary for a correct interpretation of the meaning of gunshot injuries on the field.

Our own conclusions would, therefore, exactly coincide with those of La Garde, who says: "From the foregoing I believe we should conclude that the work of the experimenters agrees with the conditions found in war, and that their work was not done in vain."