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Fleet Surgeon, R.N.

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IT would be no exaggeration to say that practically all organisms both in the vegetal and animal worlds have some means or other of defending themselves against the onslaughts of their natural enemies. Animals have not only a means of defence, but of offence as well.

In the hurry and bustle of modern times we are apt to look with unconcern, born of familiarity, on the most wonderful and ingenious machines without stopping a moment to reflect how and why they have come to be the beautiful and intricate pieces of mechanism they are. There is a direct continuity through incalculable and almost imperceptible changes from the primitive savage in the distant past blowing across the open end of a reed-stalk and the expert organist of to-day playing a complicated fugue on the organ. The modern grand piano is the twentieth century representative of a primeval taut string. In a similar way the weapons of offence and defence as exemplified in our modern ordnance have had a definite descent by modification from simpler, less differentiated forms.

The desired purpose of all weapons, whatever their nature, is destructive work; in other words, the expenditure of energy upon the somatic tissues of an adversary. Doubtless the most primitive injury ever inflicted by one organism upon another was that of simple impact; after enormous lapses of time certain parts of the organism became differentiated and specialised into spines, teeth, claws, horns, etc.; and the hurt of a simple impact gave place to the more effective hurt of impact *plus* penetration.

An obvious drawback to the use of such weapons as those just alluded to was that it necessitated the aggressor and his foe coming into actual contact, thereby exposing the former to the risk of injury at the hands of the latter. When, however, intelligence dawned on the stage of life in the person of primeval man, means were speedily taken to get over this difficulty. Experienee taught that the heavier the impinging mass and the quicker it moved the greater was the amount of mischief that could be inflicted, and so the simple closed fist became replaced by the fist clenching a stick or stone, and, from this stage to the next, in which the contents of the fist were flung directly at the enemy, was one fraught with such obvious advantages that little hesitation could have been made in adopting it; even the apes of to-day appreciate the mechanical advantage of using cocoanuts and stones as missiles against their molesters, Here, then, we have a body driven through the air by an impelling force. Within such a moving body or mass, which we may now term a projectile, the potential energy of muscle[1] has been transformed into molar energy ultimately destined to effect disintegrating changes within the tissues of an adversary. Such was the first intelligent use of the projectile as a belligerent implement.

However, at this stage prehistoric man was confronted with a serious check : unaided he could only lift a certain weight and could only give to that weight a very limited velocity. After a certain non-progressive period of marking time he suddenly awoke to the fact that a sapling when forcibly bent from the straight and then released would return to its original position with the display of a considerable amount of energy, and the idea struck him that such natural forces might well be harnessed. Acting upon this suggestion he proceeded to construct bows with which he shot forth arrows, catapults by means of which he threw out heavy javelins, and ballistae with which he hurled huge stones. Even then, however, the whole of the kinetic energy of the projectile had still to be obtained from the potential energy of his muscles, these instruments being merely receptacles for temporarily storing this energy up. Once again the weight and velocity limit was reached, and it was not until the discovery of gunpowder that a fresh and startling impetus was given to the science of ballistics.

The first discovery of gunpowder probably originated in the primeval methods of cooking food by means of wood fires on a soil impregnated with nitrates, as in many parts of India and China, for when the fires were extinguished a certain amount of charcoal would remain and get covered in the course of a few days with saltpetre, thus bringing into accidental contact two of the most active ingredients of gunpowder. Whenever a fire was rekindled in the same spot a deflagration ensued which could not fail to attract attention. The ancient Hindoos, long before the Christian era, knew the art of projecting heavy bodies by means of gunpowder, as the following paragraph from their

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[1] The potential or internal energy of the muscle-cell has, of course, been derived, like that of an engine, from outside sources. The living substance, or protoplasm of the muscle-cell exists in loose chemical combination with exceedingly complex and unstable substances derived and built up from less complex and more stable substances existing in the food-stuffs consumed by the animal. Given a certain stimulus, usually a nerve-impulse from the central nervous system, the muscle-cells respond, that is to say, the complex substances inside them suddenly break up, in fact, "explode," into simpler and more stable ones, and in this way energy is liberated, or, to be more correct, becomes transformed from the potential to the kinetic state. Just as several thousands of foot-pounds of energy may be liberated in a 12-inch gun by an insignificant pull upon an electric trigger, so the energy manifested by the muscles of an animal bears absolutely no quantitative ratio to the "stimulus" producing the responsive act of contractility.

code will show :—" The magistrate shall not make war with any deceitful machine, or with poisoned weapons, or with cannons or guns, or any kind of firearms, nor shall he slay in war any person born an eunuch, nor any person who, putting his arms together, supplicates for quarter, nor any person who has no means of escape."

By the use of this mixture the kinetic energy of the missile of war was obtained from the potential energy of an explosive quite irrespectively of the physiological energy of the warrior. Primitive cannon, "gunnis" and "bombardes" thereupon came into being, and it is worth noting that the first guns used were breech-loaders. In 690 A.D. the Arabs used cannon at Mecca, and in 1098 A.D. the Greeks had "fire-tubes" built into the prows of their war-boats. In 1449 A.D. hand-cannon were employed, which later gave way to the hand-culverins and hand-guns of the 15th century. In 1527 A.D. the Spaniards made use of arquebuses and matchlocks. In 1630 A.D. wheel-locks came into existence, but were soon ousted by the more handy flint-locks, which remained in use in the British Army until 1840 A.D. From the flint-locks emerged the muskets and later the breech-loading rifles—first the smooth-bore and then the rifled-bore—until the present stage of the modern small-bore magazine rifle was reached. The later phases of the evolution of the modern rifle are shown in Table I.

TABLE I.

Showing the Evolution of the Small-Bore Rifle.

In the year	1400	the Arabs	... ..	made use of a	1·250	inch bore rifle
,,	1500	England	... ...	,,	1·000	,,
,,	1500	,,	... ...	,,	0·750	,,
,,	1849	,,	... ...	,,	0·750	,,
,,	1850	,	... ...	,,	0·693	,,
,,	1852	,,	... ..	,,	0·577	,,
,,	1854	Austria	... ...	,,	0·550	,,
,,	1860	Sweden	... ..	,,	0·488	,,
,,	1866	France	... ...	,,	0·433	,,
,,	1867	Austria	... ..	,,	0·420	,,
,,	1869	Switzerland	... ...	,,	0·400	,,
,,	1878	Sweden	... ...	,,	0·396	,,
,,	1879	Turkey	... ...	,,	0·350	,,
,,	1888	Austria	... ...	,,	0·315	,,
,,	1888	Germany	... ...	,,	0·311	,,
,,	1889	England	... ...	,,	0·303	,,
,,	1889	Belgium	... ...	,,	0·301	,,
,,	1889	Switzerland	... ...	,,	0·295	,,
,,	1892	Spain	... ...	,,	0·276	,,
,,	1892	Holland	... ...	,,	0·256	,,
,,	1895	United States	... ...	,,	0·236	,,

The rifle is a thermodynamic machine which does its work in a single stroke and in which the potential energy of an explosive is converted into the kinetic energy of a moving projectile. Rifles may be classified according to the method in which charge and projectile are inserted as muzzle-loading and breech-loading, according to the diameter of the bore as large- and small-bore, according to the condition of the internal barrel as smooth- or grooved-bore, according to their firing capacity as single-shot and repeating.

Muzzle-loading and smooth-bore rifles are already obsolete. Single-shot and large-bore rifles are still hovering about the borderland between ancient and modern, but the universal tendency, both in big game shooting and warfare, is towards the adoption of the small-calibre rifle with a repeating system.

It would be out of place in such a paper as the present to enter into an elaborate description of any rifle, but the writer craves the reader's indulgence while he just touches upon some of the cardinal points of those weapons which have come under his personal observation in the Filipino-American and Anglo-Boer wars.

The *Snider* rifle was a not uncommon weapon in the hands of our late enemy. It has a calibre of 0.577 inch and fires a bullet of 480 grains with a charge of 70 grains of black powder. The barrel is 39 inches long and rifled by three grooves with a right-handed twist of one turn in 78 inches. The initial velocity is 1,240 f.s., the remaining velocity at 2,000 yards is only 196 f.s. The projectile has a hollow base, which renders it peculiarly deformative in character.

The *Springfield* rifle was the dreaded "Long Tom" used by the Americans against the Filipinos. It is a 0.45-inch rifle with a barrel of 32.50 inches in length, furnished with three grooves, making one complete turn in 22 inches. Seventy grains of common powder give a 500 grain bullet a muzzle velocity of 1,301 f.s., which falls to 404 f.s. at 2,000 yards.

The *Remington* rifle was the principal weapon used by the Filipinos. The barrel is a little over 35 inches in length, and possesses five right-handed spirals making one complete turn in 20 inches. The charge is 80 grains of black powder for firing a 0.44-inch bullet with an initial velocity of 1,340 f.s., which drops to 350 f.s. at 2,000 yards. This bullet is sheathed with brass.

The *Martini-Henri* rifle was sometimes used by the Boers in the late war. The barrel is 33.18 inches long and has seven grooves with a right-handed twist of one turn in 22 inches. A 480-grain bullet is given a muzzle velocity of 1,315 f.s. by means of 85 grains of black powder and a remaining velocity, at 2,000 yards, of 389 f.s.

The *Lee-Metford* and *Lee-Enfield* rifles are for practical purposes the same, with the exception that the former carries eight cartridges and has seven grooves, the latter is 4 ozs. lighter and holds 10 cartridges and has five grooves, which are narrower and deeper than those of the Lee-Metford. These rifles have a left-handed twist of one turn in 10 inches, the barrel is 30.2 inches long. A 0.311-inch bullet weighs 215 grains and has a m.v. of 2,060 f.s. 30.5 grains of cordite give a chamber pressure of 33,600 pounds.

The *Mauser* rifle was used by the Filipinos and the Boers in the late campaigns. It has a 29-inch barrel with four grooves, which are left-handed in the 1892 pattern and right-handed in the 1896 pattern. The bullet has a short diameter of 0.284 inches and weighs 172 grains; 38 grains of nitro-cellulose give a chamber pressure of 48,800 pounds.

The *Krag-Jorgensen* rifle was used by the Americans in their recent campaigns. It has a 30-inch barrel with four right-handed grooves having an inclination of one turn in 33.3 calibres. The calibre of the bullet is 0.308 inch, and it weighs 219 grains. The charge of 41.5 grains of nitro-cellulose gives a chamber pressure of 17 tons and a muzzle velocity of 1,880 f.s.

The *Lee Straight-Pull* was also used by the Americans, more especially by their navy. The barrel is 28 inches by 0.236 inch, and has six right-handed grooves with an angle of twist equal to 5 degrees 26 minutes, or one turn in 31.8 calibres. The projectile weighs 112 grains and has a calibre of 0.243 inch. 32.4 grains of nitro-cellulose give a chamber pressure of 22 tons and an initial velocity of 2,600 f.s.

The *Mannlicher* rifle was much used by the Boers in South Africa. The barrel is 31.1 inches long and has a calibre of 0.256 inch. It has four right-handed grooves making one complete turn in 31.8 calibres. 36 grains of Troisdorf give a 0.263-inch bullet of 162 grains a muzzle velocity of 2,555 f.s. The chamber pressure is 52,640 pounds.

Let us now relinquish the specific for the general. Rifling consists in the removal of longitudinal strips of metal from the internal surface of the barrel in such a way that the grooves left may be either straight, that is, parallel to the long axis of the bore, or curved, forming a helix round the long axis of the bore. The original object of the grooves was to accommodate fouling, but their present function is to compel the bullet to revolve about a long axis. Any number of grooves from two to twelve may be present, but four is the usual number; the Express rifle has eight, the Lee-Metford seven, the Lee Straight-Pull six, the Lee-Enfield five, the Mannlicher four, the Schmidt-Rubin three and the Cape rifle two grooves.

The direction of the rifling may be right or left-handed; the Lee-Metford is an example of the latter, the projectile revolving about an axis of magnitude in such a way that, looked at from the firer's point of view, the radii of the circle formed by its transverse section move against the hands of a clock. The Mannlicher rifle has right-handed grooving and its bullet therefore revolves clock-wise, that is, the radii of its cross-section, viewed from behind, move with the hands of a clock.

The devices for compelling the projectile to rotate about its long axis and prevent it from slipping across the "lands" of the piece are various, *e.g.* :—

1. Coating the surface of the bullet with a soft metal into which the "lands" of the rifle may cut.

2. Fixing bands of soft metal around the base of the bullet.
3. Fixing studs into the projectile which fit into the grooves of the piece.
4. Making the base of the projectile hollow so that the pressure caused by the explosion may expand the cavity and force the metal into the grooves. The Pritchett bullet is a case in point.
5. By fixing a hard plug of clay or wood (as in the Snider) or a metal cup (as in the Minié) in the base of the bullet so that the force of the explosion driving the plug into the softer metal of the projectile forces the base of the latter into the rifling.
6. By fixing lateral flanges to opposite sides of the bullet which fit into corresponding grooves in the rifle. The author picked up several of these bullets, known as the "Cape rifle bullet," in Paardeburg laager. They were used by the Boers for sporting purposes.
7. By making the calibre of the projectile larger than that of the rifle as measured across the "lands." This is the modern method with sheathed bullets, the lands of the rifle cutting into the mantle of the bullet; for instance, the diameter of the Mannlicher bullet is 0.2367 inch, whereas the calibre of the rifle is 0.2569 inch.

Speaking generally, the longer the bullet and the smaller its short axis the more sharp must be the twist of the rifling, or, in other words, as the ratio of the long to the short diameter of the bullet is increased the pitch of the screw must be diminished.

The following table (Table II.) shows at a glance the increase of twist that has supervened in succeeding years.

Table II.

Showing the Progressive Increase of Rotary and Translatory Speed Concomitant with the Progressive Decrease of Calibre.

Year.	Rifle.	Muzzle Velocity.	Bore in Inches.	Twist.	Revolutions per Second.
1865	Snider	1240	0·577	1 in 78·0	190
1869	Martini-Henry ...	1315	0·450	1 in 22·0	717
1889	Lee-Metford ...	2008	0·303	1 in 10·0	2400
1893	Mannlicher ...	2427	0·256	1 in 7·8	3702
1895	Lee Straight-Pull	2500	0·236	1 in 7·0	4285

When a rifle is fired the following four principal movements occur:—

1. Translation.
2. Rotation.
3. Undulation.
4. Flexion.

These movements we will now proceed to discuss separately and somewhat in detail.

1. *Translation.* A backward movement known as *recoil* begins directly the bullet advances along the bore of the rifle, in fact the rifle is actually driven off the bullet towards the rear. Recoil depends upon the weight of the rifle and projectile, the velocity imparted to the latter and the friction to which it is subjected within the bore. The recoil energy of the old Martini-Henry was considerable, being about 14 foot-pounds as contrasted with 5½ foot-pounds for the Lee-Metford.[1]

Now the greater part of this energy is absorbed by the firer's right shoulder, and after many days' prolonged firing the bruising effects are considerable, especially in soldiers of slender build. The writer has seen men in action firing, not only from the left shoulder, but from the armpits and even from the hips on account of pain, swelling and tenderness set up by the powerful recoil of the older and heavier type of fire-arm.

2. *Rotation.*

a. Consequent upon the reaction to the force expended in imparting rotation to the projectile is produced a rotation, in an opposite direction, of the rifle itself. Unless the weapon be held loosely at the instant of pulling the trigger this movement is not perceptible, being unconsciously checked by the momentary contraction of the firer's pronator or supinator muscles, according to the direction of the twist of the rifling. Now since the supinators are the stronger of these two sets of muscles we have a scientific vindication of the right-handed spiral.

b. There is also a slight rotation of the muzzle independently of the breech, a kind of "rotary fillip."

3. *Undulation.* The pressure exerted upon the internal surface of the barrel is considerable. For instance, in the Mauser rifle it is 51,000 lbs. per square inch. In consequence of this pressure there is a dilation of the barrel which takes the form of a wave advancing from breech to muzzle, the crest of

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[1] The formula for calculating the energy and velocity of recoil is:—

$$E = \frac{W\left(\frac{w\,v}{W}\right)^2}{2\,g}$$

and $V = \frac{w\,v}{W}$ since the momenta are equal.

In this formula E represents the energy of recoil in ft. lbs.
V ,, ,, velocity of recoil in f.s.
W ,, ,, weight of the rifle in lbs.
w ,, ,, ,, ,, bullet in lbs.
v ,, ,, muzzle velocity.

the wave following in the wake of the base of the bullet. Any tight ring around the barrel will interfere with the progress of this wave, in fact, will cause it to "break," with the result that the barrel is ruptured with perhaps disastrous consequences to the firer.

4. *Flexion.*

a. *Vertical "Jump."* Since the centre of gravity of the rifle is below the long axis of the bore, a thrust backwards along this line must throw the barrel in an upward direction, the rifle rotating in a vertical plane about an axis which is the point of contact with the shoulder. It is measured by the angle in a vertical plane between the axis of the piece before firing and the line of departure of the bullet.

b. *Vertical "Fillip."* In vertical jump there is a lagging behind of the muzzle, which has to describe a larger arc than the breech. Consequently the long axis of the barrel assumes a curve with the convexity upwards. Vertical fillip might be defined as the angle in a vertical plane between a tangent to the long axis of the barrel at the breech and the line of departure.

c. *Lateral "Jump."* In most rifles the centre of gravity is not in the median vertical plane, but to one side of it; in this way a lateral jump is produced, being the angle in a horizontal plane between the axis of the piece before firing and the line of departure.

d. *Lateral "Fillip."* For a similar reason to that mentioned under lateral jump, a lateral fillip is produced, and its amount is indicated by the angle in a horizontal plane between the axis of the piece before firing and the line of departure.

There are only two occasions in which a rifle bullet travels in a straight line, to wit, when the line of departure is vertically upwards or downwards, the trajectory then being the shortest distance between the muzzle and the point of impact. On all other occasions the line of departure is towards a point situated above the objective and the trajectory is a curved line. This elevation, as it is termed, is necessary in order to neutralise the fall of the projectile due to gravity: this fall is considerable, being as much as six feet in 300 yards, or 1,000 feet in 2,500 yards.

Many factors have to be taken into consideration in calculating elevation, *e.g.*, the temperature and pressure of the atmosphere and the amount of moisture either suspended or dissolved in it; the velocity and direction of air currents and—a point of theoretical import only, at any rate as regards rifle projectiles—the earth's rotation. The immense importance of temperature and pressure as factors bearing on accuracy of shooting was forcibly brought home to us in South Africa, where our rifles, originally sighted for 60 degrees Fahr. and normal sea-level pressure, had to be used at a height of 5,000 or more feet with the thermometer hovering around 90 degrees.

In consequence of the universal tendency during recent years towards the adoption of narrower and more elongated projectiles there has been, for any given range, a parallel diminution in the amount of elevation required. The following diagram (Fig. 1) shows the increase of dangerous zone consequent upon this depression of the line of sight.

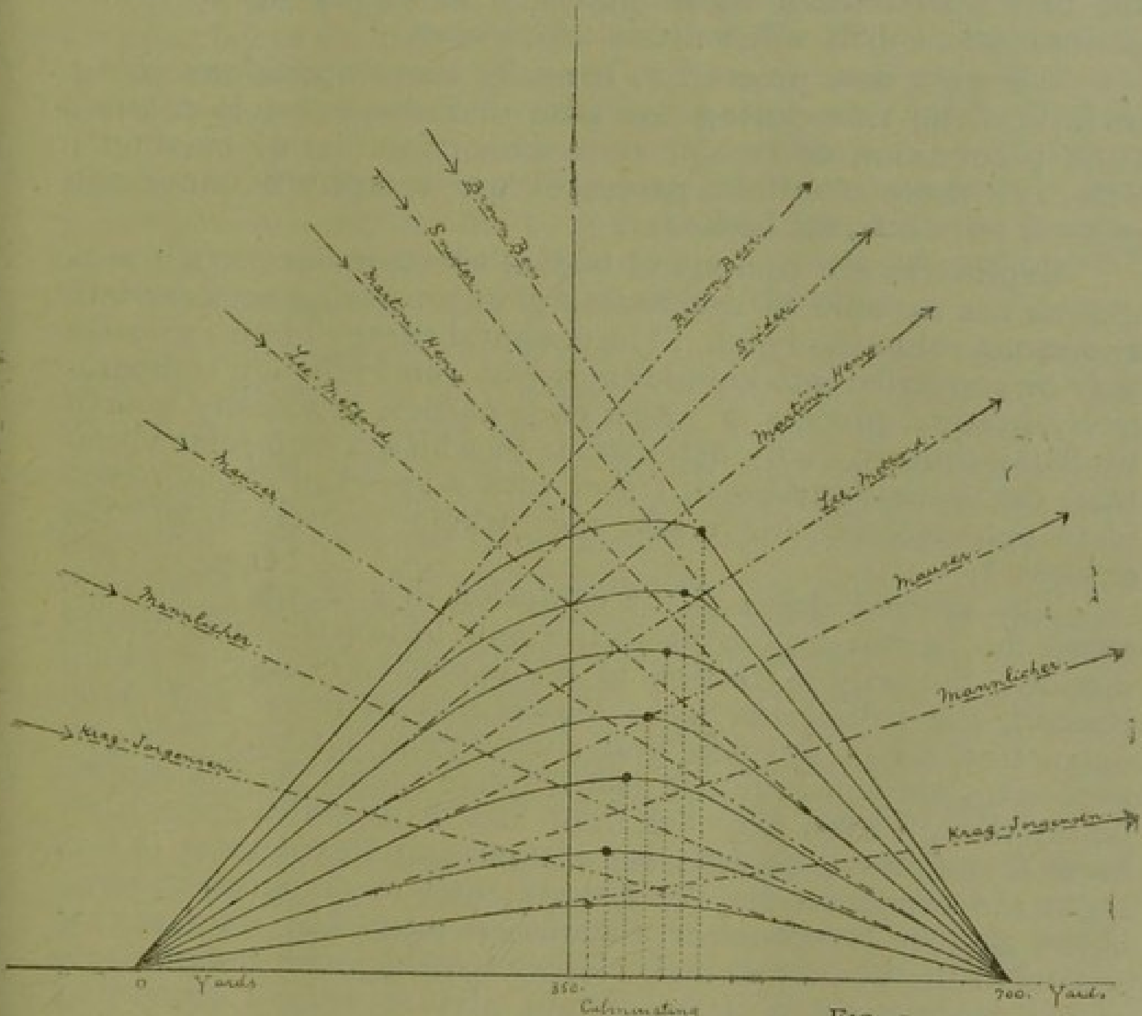

FIG. 1.

In Fig. 1, which is, of course, purposely exaggerated and purely diagrammatic, it will be seen that for a range of 700 yards the old Brown Bess bullet had a dangerous zone of 50 yards, *i.e.*, 7.1 per cent. as compared with the modern Krag-Jorgensen bullet, which for a range of 700 yards has a dangerous zone of 700 yards, *i.e.*, 100 per cent. Taking other rifles into consideration, we find that for a range of this distance the dangerous zones are as follows:—

Brown Bess	·750 in. bore	...	50 yds. 7·1 per cent
Snider	·577 ,,	...	150 ,, 21·4 ,,
Martini-Henry	·450 ,,	...	200 ,, 28·5 ,,
Lee-Metford	·303 ,,	...	400 ,, 57·1 ,,
Mauser...	·276 ,,	...	630 ,, 90·0 ,,
Mannlicher	·256 ,,	...	650 ,, 92·8 ,,
Krag-Jorgensen	·236 ,,	...	700 ,, 100·0 ,,

At 1,000 yards range in a calm atmosphere it will be found that a Lee-Metford bullet has an error of about three feet to the left, the Mauser bullet has an approximately similar deviation to the right. The cause of this error is three-fold, lateral fillip and jump (which have just been discussed) and "drift"—a movement of the projectile due to its rotation about a long axis. The direction of the drift depends upon the inclination of the spiral of the rifle; when this is left-handed the derivation is to the firer's left; when right-handed it is to his right. The mechanism of drift will be considered later.

We must now proceed to consider those operations going on within the rifle during the time that the bullet is passing from a condition of rest or zero velocity to one of maximum velocity; these manifold processes are comprised under the general term *internal ballistics*.

Explosives are compound bodies which under certain conditions are capable of decomposing in an abrupt manner into enormous volumes of gas. The potential energy of an explosive may be converted into kinetic energy by *combustion*, a comparatively gradual process in which each particle is actually ignited by flame-contact, or by *detonation*, in which a molecular vibration, calculated by Abel to travel with a speed of about 19,000 feet per second, traverses the whole substance of the explosive.

The avowed object of the explosion of a charge is to overcome the inertia of the projectile and to impart to it certain motions, but only a fraction of the explosive energy is so expended, the remainder being represented as molar and molecular motions of the rifle and surrounding media. "High" explosives are more suitable as disruptive agents than as propellants; though even here the limit has, it seems to the writer, been sometimes exceeded; for instance, at Paardeburg it was quite the exception for the lyddite shell to do much damage either against *personnel* or *matériel*, as proved by the fact that several of the Boers had their clothes splashed with the products of the decomposition of the picrate mixture without sustaining severe bodily injuries, and also by the fact that after explosion the fragments of the shell seldom travelled far, being usually found huddled together in and close around the site of the explosion, as though the rise of pressure within the shell cavity had been so sudden that sufficient time was not allowed to overcome the inertia of the shell fragments. It is expected, however, that in a naval war very different results would ensue from the use of lyddite; bursting inside the comparatively circumscribed spaces of casemates or "'tween-decks" the sudden rise of pressure consequent on the production of enormous volumes of gases would play havoc with the surrounding structures and kill all those in the immedite vicinity; moreover, the asphyxiating character of the products of explosion would convert all adjacent compartments into veritable lethal chambers.

With "low" explosives there is a comparatively gradual rise of pressure within the chamber of the rifle, but long before the combustion of the charge is completed the projectile begins to move towards the muzzle of the rifle with accelerating velocity, and although the chamber pressure begins to fall before the projectile has left the muzzle, combustion is still going on and gas being generated the whole time it is advancing down the barrel.

Were the projectile fixed and immovable the pressure in the chamber of an ordinary rifle would rise to about 100,000 lbs. per square inch, but the moment the projectile begins to move space is increased and the pressure of those gases already formed falls, though the total pressure is still rising. The chamber pressure of the Mauser and Lee-Metford rifles respectively are 51,000 lbs. and 42,000 lbs. to the square inch, and the corresponding pressures upon the base of these projectiles are respectively 2,625 lbs. and 2,982 lbs. chamber thrusts.[1]

The ideal propellant is one which is burning the whole time the projectile is in the barrel of the rifle, but which has its last grain ignited as the projectile leaves the muzzle. A hard and fast line cannot be drawn between powders that decompose by detonation and those that decompose by conflagration, and even the same powder may behave differently in this respect under different conditions; for instance, a rise of temperature and pressure increases the rapidity of decomposition, and a powder that under normal conditions "burns" may have its surrounding temperature and pressure so raised that the latter part of the charge "detonates" and in this manner most grave injuries have resulted from the bursting of the gun or rifle, more especially with the use of sporting powders.

In South Africa during the late war the cartridge cases of some of the guns got raised by the sun to so high a temperature that it was impossible to manipulate them with the naked hand; when such cartridges were fired it was noticed that the projectiles

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[1] The *mean* thrust upon any projectile may be calculated by the following formula :—

$$T = \frac{M V^2}{2 g (l - c)}.$$

Where T = mean thrust in pounds upon base of bullet.
,, M = weight of bullet in lbs.
,, V = muzzle velocity in feet-seconds.
,, g = gravitation force.
,, l = length of barrel in feet.
,, c = length of charge in feet.

For the Lee-Metford bullet T = 824 lbs., and for the Mauser bullet T = 845 lbs.

invariably overshot the mark, but our gunners were not long in making the requisite diminution of elevation.[1]

When we have to deal with pressures of 40,000 lbs. to 50,000 lbs. to the square inch (in fact, in the Parraviçino-Carcano rifle of the Italians the pressure amounts to as much as 60,000 lbs. per square inch) it is not surprising that the energy of the modern bullet is so marked. We must, however, be careful to distinguish between energy and momentum; for instance, a 215 grain Lee-Metford bullet with a velocity of 2,000 f.s. has the same momentum as an Express bullet of twice this weight and half this speed, but the energy of the Lee-Metford bullet is double that of the Express. The amount of motion a projectile possesses is termed its momentum, its capacity for doing *work* is called its energy, double its mass and the energy is duplicated, but double its velocity and a fourfold increase in the bullet's capacity for doing work is obtained.

The bullet has its maximum energy at the moment that its base is in the act of leaving the muzzle; the following diagram (Fig. 2) is intended to show the relation existing between the pressure upon the base of the bullet and its velocity and energy while travelling down the bore of the rifle:—

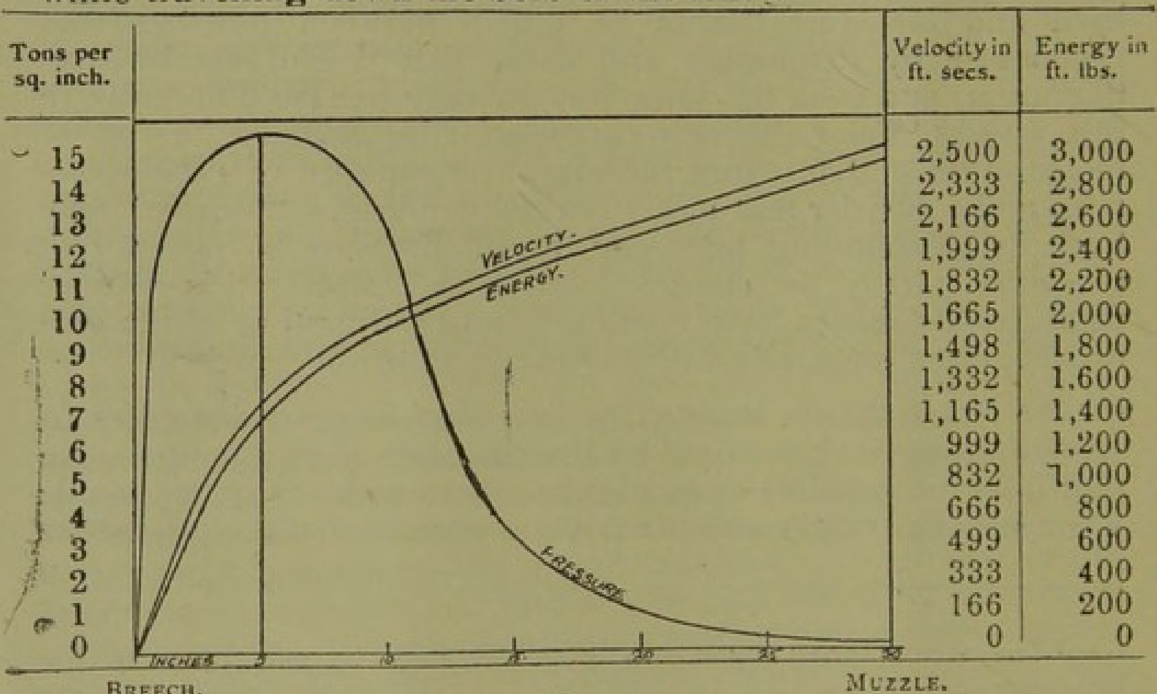

FIG. 2.

Diagram showing velocity, pressure and energy curves of a bullet in its passage down the rifle barrel.

[1] The effect of temperature upon the pressure exerted by an explosive has been shown in a most vivid manner by Noble. He exploded, in a closed vessel, 28 ozs. of cordite, noting the pressure after certain intervals of time, thus:—

After	0.07	seconds	the pressure was	6	tons	per square inch.
,,	0.17	,,	,,	5	,,	,,
,,	0.73	,,	,,	4	,,	,,
,,	1.76	,,	,,	3	,,	,,
,,	3.32	,,	,,	2	,,	,,
,,	7.08	,,	,,	1	,,	,,

The actual amount of *work* capable of being done by the modern small-bore bullet upon the animal economy is very considerable, from 1,800 ft. lbs. to 2,800 ft. lbs. With hard-sheathed bullets only a small fraction of this work is, under normal conditions, expended upon the somatic tissues; with bullets which are devoid of a mantle or possess one that has been purposely weakened at certain points, or again in sheathed missiles suffering from aberrations of flight, errors of form or a want of homogeneity in structure, the whole of the energy may be converted into destructive work performed upon the anatomical elements. In civilised warfare the former condition is aimed at, the ideal being to place the enemy temporarily out of action without condemning him to become a permanent cripple; in war against fanatical tribes and in big-game shooting, the latter condition is contemplated, we hope to kill and to kill quickly.

Since the bullet's energy decreases with the distance covered and since the capacity of the bullet for doing work of a harmful nature upon the living body depends directly upon the energy with which it is endowed at the moment of impact, it follows that if the soldier, the sportsman or the surgeon wishes to be able to predict the particular traumatic phenomena that may be exhibited in the body of the victim at various ranges he must have a clear idea what the energy of the projectile will be after it has covered any definite distance; in short, a knowledge of the *remaining energy* of the bullet at any point of its flight is absolutely essential. Let us take the 0.256 inch Mannlicher bullet as an example; at the muzzle this missile can strike a blow of 1,581 ft. lbs., at 500 yards the energy is only 568 ft. lbs., at 1,000 yards it is 257 ft. lbs., at 2,000 yards it is 86 ft. lbs., and at 3,000 yards the exhausted bullet can scarce strike a blow of 30 ft. lbs.

Hithereto we have considered velocity and energy of the bullet only in connection with its motion of translation; we must now examine its speed and energy of rotation.

The rotary energy of the modern bullet is a factor which the military surgeon cannot afford to despise; for instance, this energy in the Lee-Metford bullet at the commencement of its career is 17.2 ft. lbs.[1]

[1] The energy in ft. lbs. of any bullet due to its rotation is :—

$$\frac{W}{2g}(rA)^2$$

In which W = weight of bullet in lbs.
,, r = radius of gyration in feet.
,, g = gravitation.
,, A = angular velocity in ft. secs.

Given the rifle we can state the energy of rotation of the bullet thus :—Let R. be the energy of rotation, p. the pitch of the rifling in ft., r. the radius of gyration in ft., w. the weight of the bullet in lbs., v. its velocity in ft. secs., and g. gravitation, then :—

$$R=\left(\frac{4\pi^2 r^2}{p^2}\right)\left(\frac{w v^2}{2g}\right)$$

The muzzle velocity of rotation depends upon muzzle velocity of translation and screw pitch, and can be found by dividing the latter velocity by the pitch of the screw, thus for the Lee-Metford bullet the muzzle velocity of rotation is $\left(2{,}000 \div \frac{10}{12}\right)$, *i.e.*, 2,400 revolutions per sec.[1]

Under the heading of *internal ballistics* we considered the projectile in its passage through the rifle, its course being then for all practical purposes a right line; we must now take up the question of *external ballistics* and study the behaviour of the projectile after it has left the rifle, and in this connection we must first consider the projectile in its flight through the air, *i.e.*, before impact, and, secondly, in its passage through the more or less solid medium, termed the objective, *i.e.*, after impact.

As the bullet enters the outer world it finds itself, so to speak, under very different conditions to those under which it existed before it was acted upon by the force of the explosion; it is now describing an orbit through space at high speed, it is rotating about an axis of magnitude with a velocity which may be anything between 144,000 revolutions and 257,000 revolutions per minute (the former in the case of the Lee-Metford and the latter in the Krag-Jorgensen), it possesses a high capacity for work, its surface is clean, bright and highly polished by the removal of the superficial layers of the sheath, it is furrowed by several parallel straight grooves, its temperature is raised, partly by the enkindled gases, and partly by the friction to which it has been subjected while coursing through the barrel; in consequence of this rise of temperature it is thoroughly sterilised, that is to say, is totally destitute of all living bacteria and their spores.

Standing behind a 12-inch gun one can easily follow the flight of the projectile with the naked eye. Under favourable circumstances and with the aid of a telescope it is possible to catch a glimpse of even the small-bore bullet as it flashes through the air. Photographs, or rather shadowgraphs, of the 0.311-inch bullet travelling with a speed of over 2,000 f.s. have been obtained, and they clearly show the cap of condensed gas, about one-tenth of an inch thick, which clothes the ogive of a projectile when it is in rapid motion through a gaseous medium. From

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[1] The linear velocity of rotation is the tangential speed of any point on the surface of the bullet, or the velocity with which such point revolves around the median long axis. For the Lee-Metford bullet the linear velocity of rotation is 190.3 ft.-secs., and is calculated as follows:—Let L. represent the linear velocity of rotation, r. the muzzle velocity of rotation, d. the diameter of the bullet in ft., then:—

$$L = \pi r d.$$

Angular velocity of rotation is the number of units of angular measure revolved through in one sec. A bullet making one turn in one sec. has an angle velocity of 2π or 360 degrees, hence, the Lee-Metford bullet has an angle velocity of $4{,}800\pi$ or 864,000 degrees.

the shoulders of such a projectile straight lines may be seen to diverge posteriorly, symmetrically to the trajectory; secondary divergent lines forming somewhat more acute angles, proceed from the basal cannelure—if present; the angles formed by these lines with the trajectory increase as velocity diminishes. Minute rotating spherules of gas showing vortical motion remain behind and map out the path of the bullet. These lines and eddies recall forcibly the bow and stern waves made by a ship in motion and the numerous little whirlpools that may be seen in its wake.

The sound made by the projectile as it courses through the air is a rough indication of its velocity. At low velocities the displaced air immediately glides in behind the base of the bullet just as the water displaced by the bows of a ship closes in behind the stern, and the sound emitted is a prolonged hum or whizzing note; at high velocities a vacuum is formed behind the posterior surface of the projectile and a sharp abrupt detonating noise, like the crack of parchment under tension, is heard, due to the collisions of the displaced columns of air. All who have marked inside rifle-butts or who have been present in a "raking" ship at target practice afloat are familiar with the peculiarly sharp and abrupt noise made by a projectile in rapid motion.

The effect of rotation upon the flight of the projectile is extremely interesting and instructive. The rotations of the projectile may be divided up as follows:—

1. *Rotations in the vertical antero-posterior plane.*
   - *a.* Forward rotation about a long axis.
   - *b.* Forward rotation about a short axis.
   - *c.* Backward rotation about a long axis.
   - *d.* Backward rotation about a short axis.

2. *Rotations in the vertical lateral plane, i.e., in the plane at right angles to* 1.
   - *a.* Right-handed or clock rotation about a long axis.
   - *b.* Right-handed or clock rotation about a short axis.
   - *c.* Left-handed or anti-clock rotation about a long axis.
   - *d.* Left-handed or anti-clock rotation about a short axis.

3. *Rotations in the horizontal plane.*
   - *a.* Right lateral rotation about a long axis.
   - *b.* Right lateral rotation about a short axis.
   - *c.* Left lateral rotation about a long axis.
   - *d.* Left lateral rotation about a short axis.

The majority of these rotations, which may, of course, occur in any one of the three planes of space, are not normal to the bullet's flight, but are brought about by errors of propulsion, eccentricities of the bullet's conformation or structure, or by the reaction to impact, one or a compound of these abnormal rotations being invariably present in every ricochetted missile.

The revolution speed of the bullet does not decrease so rapidly as does the speed of translation, hence rotary phenomena are more marked at long than short ranges. In striking a person at an extreme range the bullet may enter the body but fail to emerge, rotating rapidly within the tissues until friction brings it to rest. That this rotation plays a significant rôle in the genesis of projectile injuries will not be denied by those who appreciate the significance of a rotary speed of 2,000 revolutions to 4,000 revolutions per second. Let us now consider these rotations somewhat in detail.

Forward Rotations.—The bullet rotates about a lateral horizontal axis, its equator of rotation moving in an antero-posterior vertical plane in such manner that a point on the most anterior part is, at any instant of time, advancing in a downward direction relative to a point on the most posterior aspect of the bullet which has a tangential direction upwards. These rotations are abnormal, being subsequently acquired by ricochet with the ground or other horizontal surface below the bullet.

Backward Rotations.—The projectile rotates about a lateral horizontal axis, its equator of rotation moving in an antero-posterior vertical plane in such manner that any instant of time the most forward point is ascending relative to the most posterior point which is descending. These rotations are also abnormal, being acquired after the bullet has ricochetted off a horizontal surface *above* it.

Clock or Right-handed Rotations.—The bullet rotates about an antero-posterior axis in such manner that the equator of rotation is in a lateral vertical plane, and an observer situated behind the bullet, *e.g.*, the firer, would, if it were possible, note that the radii of revolution moved with the hands of the clock. This rotation, when it is about the bullet's median longitudinal axis, is the normal rotation imparted by rifles such as the Krag-Jorgensen with a right-handed twist.

Anti-Clock or Left-handed Rotations.—The bullet rotates about an antero-posterior axis in such a manner that the equator of rotation is in a vertical lateral plane, and the firer would see the radii of revolution moving against the hands of a clock. This rotation when about an axis of magnitude is normal to bullets fired from rifles with a left-handed twist, *e.g.*, the Lebel and Lee-Enfield.

Right Lateral Rotations.—The bullet rotates about a vertical axis, its equator of rotation lying in a horizontal plane with its most advanced point moving at any instant of time to the firer's left hand, its most posterior point moving towards his right hand. These are abnormal rotations caused by ricochet from a vertical plane to the left of the firer. If, however, a bullet with clock rotation undergoes a tilting motion so that it points upwards with its long axis hanging vertical, it is easy to see that the rotation normal to the bullet has been shifted from the vertical to the horizontal plane, so that the bullet, though still rotating normally as regards its own dimensions, now possesses right lateral rotation. This is the particular rotation that causes a drift to the right.

Left Lateral Rotations.—The bullet rotates about a vertical axis, its equator of rotation lying in a horizontal plane with the point most distant from the firer moving towards his right hand, the proximal point moving to his left. These are abnormal rotations produced by ricochet off a solid vertical plane on the firer's right hand aspect. If, however, a bullet with anti-clock rotation becomes so tilted that it points upwards, its long axis vertical, the rotation normal to the bullet has undergone transference from the vertical to the horizontal plane, so that, though still rotating normally as regards its own dimensions, the projectile now possesses a left lateral rotation. This is the rotation that causes drift to the left.

We have here enumerated merely the six primary rotations of the projectile in the three dimensions of space, but there remain innumerable rotations which are compounded out of one or more of these six fundamental kinds, for instance, there are the various "humming-top," "hour-glass," and "pirouetting" movements to which we will allude later when discussing the passage of the projectile through solid media.

Let us now consider the action of winds upon the rotating projectile. The first effect of an air current is obviously to induce motion in its own line of direction. When the wind is strong and from the side, and when the flight is prolonged, and especially when the bullet is attenuated in form and light in weight, this imparted motion is very considerable, thus at a thousand yards' range and with a sixty-mile-an-hour flank wind the Lee-Metford bullet undergoes 44 yards deflection.[1]

The second effect of air currents depends upon the species of rotation with which the bullet is endowed and is to induce a motion of translation whose direction is at right angles to that of the air current. The wind produces a cushion of condensed air in contact with that side of the bullet opposed to it; on the sheltered aspect of the bullet is a zone of rarefied air. The result of this is a difference of pressure upon the two sides of the projectile, and hence if the rotary motion be such that the circumference of maximum rotation passes through these alternate zones of condensation and rarefaction it must induce a movement of translation at right angles to the direction of the wind, on precisely the same principle that a billiard ball rotating in a vertical plane and dropped from a height of an inch or so upon the cloth will have a portion of its motion of rotation arrested and converted into one of translation. It will not be necessary here to do more than merely enumerate in tabular form the resultant motion of the projectile brought about by this reaction between its surface of rotation and the wind.

([1]). If the wind is blowing from left to right across the line of flight, it will give to the bullet a component lateral velocity in the direction of the wind and the resultant direction is $\tan^{-1} \frac{V}{v}$ where V. is the muzzle velocity and v. the velocity of the wind.

The amount of deflection can be calculated from the formula $D = v(t - \frac{r}{V})$ where D is the deflection, v. the wind velocity, V. the muzzle velocity, r. the range and t. the time of flight.

With cylindro-conoidal bullets possessing normal rotation about a long axis (clockwise in the case of rifles with a right-handed twist and anti-clockwise in the case of rifles with an opposite twist) it will thus be seen that the effect of a wind from the firer's right will be to cause the bullet either to ascend, in which case ranging power will be increased and the bullet will fly high of the mark, or to descend, in which case the bullet's ranging power will be diminished and it will fall short of its proper destination.

The bullet's energy of rotation is $4 \pi^2 r^2$ divided by p^2 of the striking energy where r = radius of gyration in feet and

Table III., showing the effect of air currents upon a projectile rotating about an axis of magnitude.

Direction of bullet's rotation.	Direction of Wind.	Resultant motion of translation imparted to bullet.
Rotation forward	From the front	Bullet ascends.[1]
,, ,, ...	,, ,, back	,, descends.
,, ,, ...	,, ,, right	No effect.
,, ,, ...	,, ,, left	,, ,,
,, ,, ...	,, above	Bullet recedes.
,, ,, ...	,, below	,, advances.
,, backward... ...	,, the front	,, descends.
,, ,, ...	,, ,, back	,, ascends.
,, ,, ...	,, ,, right	No effect.
,, ,, ...	,, ,, left	,, ,,
,, ,, ...	,, above	Bullet advances.
,, ,, ...	,, below	,, recedes.
,, right lateral ...	,, front	,, goes right.
,, ,, ,, ...	,, back	,, ,, left.
,, ,, ,, ...	,, right	,, recedes.
,, ,, ,, ...	,, left	,, advances.
,, ,, ,, ...	,, above	No effect.
,, ,, ,, ...	,, below	,, ,,
,, left lateral ...	,, front	Bullet goes left.
,, ,, ,, ...	,, back	,, ,, right.
,, ,, ,, ...	,, right	,, advances.
,, ,, ,, ...	,, left	,, recedes.
,, ,, ,, ...	,, above	No effect.
,, ,, ,, ...	,, below	,, ,,
,, clockwise... ..	,, front	,, ,,
,, ,, ...	,, back	,, ,,
,, ,, ...	,, right	Ascends.
,, ,, ...	,, left	Descends.
,, ,, ...	,, above	Bullet goes left.
,, ,, ...	,, below	,, ,, right.
,, anti-clockwise ...	,, front	No effect.
,, ,, ,, ...	,, back	,, ,,
,, ,, ,, ...	,, right	Descends.
,, ,, ,, ...	,, left	Ascends.
,, ,, ,, ...	,, above	Bullet goes right.
,, ,, ,, ...	,, below	,, ,, left.

[1] A driven golf ball that has been "topped," and which therefore we may regard as a spherical projectile with forward rotation under the influence of a "wind from the front," undoubtedly "ducks," as every golfer knows; but this remarkable phenomenon is open, I think, to another interpretation.—C.M.B.

p = pitch of rifling. This energy in a smooth-bore rifle would be expended in augmenting the muzzle velocity of translation, but unfortunately a bullet fired from such a rifle begins to rotate about a short axis within a few feet of the muzzle. What, then, are the objects of this rotation about the median long axis? They are :—

1. To give stability, thus keeping the point of the projectile more or less in the line of direction, and to increase penetrative capacity.
2. To diminish resistance.
3. To present the inevitable imperfections of surface to the atmosphere at all points.
4. To enable a greater mass to be fired without increase of sectional area.

At the instant an elongated projectile leaves the muzzle of a rifle there occurs a tremendous blast of gases past it, the gaseous particles having a much higher muzzle velocity than the projectile itself; now were it not for its stability acquired in virtue of its rapid rotation about a long axis the effect of these gases would be the production of a rotation about a short axis, in fact, experiment has proved that elongated projectiles fired from a smooth-bore rifle may be travelling " side on " at a distance of two feet from the muzzle, and this in spite of the fact that the smooth-bore bullet has, *coeteris paribus,* a much higher muzzle velocity.

If we watch an ordinary humming-top spinning on a smooth plate we see that at the commencement of its spin it is somewhat unsteady, its long axis generating a cone of which the frustum is the peg in contact with the plate; after a while the long axis assumes a perfectly vertical position and the top " falls asleep " and is apparently motionless; as the revolutions decrease in rapidity the top again begins to wobble until, finally, after some very erratic evolutions, it rolls over on to its side. Now a cylindro-conoidal bullet is nothing more nor less than an aerial top spinning many thousand times a minute about its long axis, its apex, corresponding to the peg of the top, rests upon a layer of condensed air, which may be likened to the plate upon which the humming-top spins; at first, owing partly to slight imperfections of the muzzle of the rifle, partly to the disturbing effects of the blast, the long axis of the bullet generates a cone in space of which the apex is represented by the extreme point of the ogive, soon, however, the projectile settles down into a condition of almost perfect stability and only begins to sway again towards the termination of very long trajectories. Screens interposed in the path of a bullet at various ranges prove that the aperture made at comparatively close range is somewhat larger than that at a moderate range, the largest holes being met with at the longest ranges. Fortunately for the stability of the bullet angular retardation is very slight as compared with the retardation of translation; in short, the projectile moves in a constantly increasing screw.

The resistance to a modern bullet's translation is the expression of work done in overcoming the inertia of air particles, thrusting them aside and imparting to them a definite velocity of translation and rotation; for instance, a 0.75-inch bullet weighing 583.3 grains has energy of 3,607 ft. lbs. at 25 feet from the muzzle, at a range of 75 feet its energy has fallen to 3,109 ft. lbs., hence in traversing 50 feet of air between the ranges 25 feet and 75 feet, 498 ft. lbs. of work are done upon air particles. This is equivalent to an average pressure of 9.9 lbs. continually thrusting the bullet backwards.

The conformation of the anterior and posterior extremities of the bullet are important factors as regards aerial resistance. Taking the resistance opposed to the tubular Krnka-Hebler bullet as unity it is found that:—

1.	Flat-headed projectiles have a resistance of	12.50
2.	Hemispherical-headed projectiles of ...	8.30
3.	Ogival-headed of one diameter of base of	6.90
4.	Hemispheroidal-headed of	6.50
5.	Ogival-headed of three radii of base ...	6.10
6.	Krnka-Hebler of	1.00

No definite expression of the relation existing between velocity and resistance has yet been found; up to velocities of 790 f.s. resistance varies as the square of velocity, between 790 f.s. and 990 f.s. as the cube of the velocity, between 990 f.s. and 1,120 f.s. as the sixth power of the velocity, between 1,120 f.s. and 1,330 f.s. as the cube of the velocity, and above speeds of 1,330 f.s. it again varies as the square of the velocity. These complex relations between speed and resistance seem to be connected with the formation of caps of condensed air in front of the projectile and partial vacua behind it. A bubble ascending through a fluid does not ascend in a right line but in a zig-zag fashion, that is, in a series of directions. This is owing to the gradually increasing pressure on the superior surface extending laterally and affecting one side more than another, the bubble-projectile consequently deviating from that side. It is conceivable, nay, probable, that a solid projectile has a somewhat sinuous course through the atmosphere owing to parallel causes, and although the amount of oscillation so produced may not be capable of actual measurement or even demonstration it may yet be sufficient to allow the projectile to make a series of scapements, as it were, from the cap of condensed air constantly forming and reforming in front of its apex; in this way it may be connected with the bizarre and inexplicable relationship existing between velocity and resistance.

The resistance of the air varies according to the area of section of the bullet, and, since the sectional area of an elongated bullet is circular it follows that when the bullet is travelling with its long axis lying at a tangent to the trajectory, resistance varies as the square of the diameter. Retardation of a bullet is the converse of its ranging power and is proportional to the area of its cross section divided by the weight.[1]

It is obvious that by narrowing the calibre of the projectile and maintaining its weight an increase of ranging power may be obtained.

A perfect bullet is a *concentric* body, the centres of gravity and form coinciding. Air cavities or vacuoles within the substance of the missile whether in the nucleus or between it and the sheath render the bullet an *eccentric* body.

In saying that the ranging power is proportional to the sectional density it is assumed that the bullet travels point first with its axis of magnitude lying constantly at a tangent to the trajectory. A concentric bullet fired vertically upwards or downwards would fulfil these conditions and strike a horizontal plane lying respectively above or below the bullet apex first with its long axis at right angles to the plane, but a bullet fired in any other direction than the vertical would have its long axis at an angle to the trajectory tangent, and the angle thus made would be a constantly increasing one with increase of elevation; in fact, an elongated projectile fired vertically upwards would retrace its path and strike the ground base first.

One would expect the bullet when trajected horizontally to strike the ground exactly *side on,* for the effect of its rotation would be such as to maintain its long axis constantly parallel to the line of departure; practically, however, this is not found to be the case owing to atmospheric resistance, which acts on the bullet in somewhat the same way that it acts upon a dart or arrow. Let us make this point clearer; with cylindro-conoidal projectiles the resistance of the air is, of course, greater to the basal half than to the apical half, consequently directly the apex of the bullet gets above the trajectory, as it is constantly tending to do in virtue of its long axial rotation, the increased pressure upon the basal portion forces it back into the line of the trajectory and thus the combined effects of atmospheric resistance and rotation are such as to cause the projectile to assume a position intermediate to the two.

A cylindro-conoidal bullet advancing in this fashion through a resisting medium must therefore always have the greatest pressure thrown upon its antero-inferior aspect and this is the key to the solution of that most puzzling phenomenon called drift or derivation, concerning the mechanism of which there has been so much contention. In consequence of this relatively augmented pressure upon the bullet's antero-inferior

[1]Let D be the diameter and W the weight of a bullet, then $\frac{D^2}{W}$ represents the comparative retardation. $\frac{W}{D^2}$ is the sectional density of the bullet and is proportional to its ranging power or capacity for maintaining velocity. For instance, the $\frac{D^2}{W}$ of the Snider bullet is 4·855 as opposed to 2·831 for the Mannlicher; in other words, given equal velocities the Mannlicher bullet meets with but one half the retardation of the Snider.

aspect a portion of the rotary motion is transformed into translation, the bullet rolling, that is, drifting, to one or other side upon these cushions of air, the particular direction assumed depending solely upon the species of rotation.

Turn we now to the second and, to the surgeon at any rate, more practical division of our study of the subject of external ballistics, to wit, *impact* and *penetration*.

When a projectile strikes its objective, work is done and is manifested in one of three ways: disintegration, partial or complete, of the objective, of the projectile or of both. Given a projectile of absolute hardness, smoothness and elasticity impinging upon an objective possessing similar transcendental characters the former would rebound off the latter with undiminished velocity and no work would have been done during impact either upon the projectile or upon the objective. If a tennis ball and an egg respectively be thrown at and strike an individual we may note that the latter, that is to say the objective, compels practically the whole of the work to be performed upon the missile; in the case of the tennis ball this work is represented by the destruction of a small quantity of motion, in the case of the egg by the destruction of all motion and a good deal of cohesion. A lead bullet which will just perforate a human body without suffering in shape may fail to even penetrate the hide of a pachyderm, flattening itself out against it; in the former case most of the work has been expended upon the objective, in the latter case upon the bullet.

The mutual reaction between the projectile and the animal's body is evidenced by deformation, heating and change of inertia of particles of both the body and the projectile. If it is desired to ascertain the actual amount of work done by the bullet in traversing, say, a human being, the energy of the bullet as it emerges from the tissues must be deducted from its striking energy, the difference representing the amount of energy absorbed by the tissues; should the bullet fail to emerge we then know for certain that the whole of its energy has been expended in ploughing its way through the softer tissues, lacerating them, and in shattering the bones. In each of these instances it has, of course, been assumed that the bullet itself has undergone no deformation.

In war it is no uncommon thing for a bullet to perforate one, two, or more individuals, the work performed upon one man being approximately $\frac{1}{n}$th the work done upon n men.

Whilst traversing the objective the projectile must excavate a tube whose cross section is equal to the cross section of the projectile; if the objective be rigid, as, for instance, a plate of bone, this tube remains open, if plastic, as in the soft tissues of the body, the tube may partially close, if liquid the tube closes quickly and completely. When the apex of the projectile comes into contact with the surface of a solid body it throws into a state of compression those particles in immediate contiguity;

surrounding this zone of approximated particles is an area of particles in a state of extension or tensile stress. As the strains set up by the bullet increase, the limit of elasticity of the particles in this strained area is ultimately overcome and the resulting solution of continuity allows of the passage of the bullet, capped by a certain number of highly-compressed particles, through the solid structure.

In the case of plastic or semi-solid materials the mechanism of the perforation is not quite so straightforward. In perforating skin, muscle, membranes, etc., the apex of the bullet first excavates a cup-shaped depression into which it insinuates itself; the zones of compression are now chiefly around the shoulders of the bullet and extend forwards and outwards in every plane. Anterior to the extreme point of the ogive is a small zone of extended particles resulting from the stretching of the tissues over it; the centre of this zone soon ruptures and into the minute opening so formed is thrust the apex of the bullet. Forcing its way onward the bullet, in virtue of its wedge action, dilates this opening and, if the constricting collar of tissues be not sufficiently elastic to allow of the bullet's passage, it becomes ruptured at four equidistant points by small rents extending radially outwards; thus are formed four moveable sectors which first bend outwards and then spring back to their original position, practically closing the aperture directly the bullet has passed.

As has already been indicated, the bullet, in traversing the tissues of the body, expends its energy in modifying the motion, destroying the cohesion and raising the temperature of the molecoles not only of the tissues but of the bullet itself.[1]

The higher the velocity and the harder the bullet the more localised are the stresses produced and the more chance is afforded the bullet of neatly perforating hard structures such as bone, and the less liable is it to suffer from the effects of its own energy. A bullet thrown by the hand will shiver a window-pane to fragments, the same bullet fired from a rifle will punch out a small hole. The work done by a bullet in traversing such a structure as bone is proportional to the product of the circumference of the missile into the thickness of bone perforated when the incident angle is a right angle; if perforation be effected at an oblique angle the work done is proportional to the direct perforation into the sine of the angle of incidence.[2]

The modern bullet will perforate and refuse reflection at a much more acute angle than the older bullets, which were turned aside at an angle of 70 degrees. The critical angle depends

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[1]The amount of *work* done by the bullet within, and upon the human body, is in the absence of deformation of the bullet, $\frac{W(V-V')}{2g}$ where W. is the weight of the bullet in lbs., V. the velocity of entrance, and V'. the velocity of emergence in ft. secs., and g. gravitation.

[2]Let d. be the bullet's diameter and T. the thickness of bone perforated, and W. the work done in effecting this perforation, then $W = \pi d T^2$.

upon the material of the objective and upon the shape of the projectile's head and also upon the velocity and mass of the bullet. After reflection off a plane surface the angle of reflection is greater than the angle of incidence and their respective planes do not coincide, but form an angle on account of the change of direction set up by rotation at the moment of impact.

Table IV. will give an idea of the comparative perforative powers of various bullets in gaseous, liquid and solid media. The perforation of air, that is to say the maximum theoretical range, has been calculated by means of Bashworth's formula and is quoted for the sake of comparison only, for in practice such enormous distances are never realised owing to the bullet's horizontal motion being arrested by contact with the ground. All the remaining perforations have been obtained by taking actual measurements of the bullet's track through the various media. The measurements 12 to 20, excluding 15, were calculated from previous measurements of tracks made with bullets travelling at reduced speed.

In the older days of low velocity bullets with feeble penetrative capacity, contusions were not infrequent; now they are seldom seen. The writer, when in Malinta in Luzon, once saw a most curious injury in the person of an American trooper who presented himself with an enormous black bruise involving the whole of the front of his trunk, the skin being unbroken at any point. When his faintness and partial collapse had passed off he described what had happened. It seems that he had gone into action with a small 3-16ths-inch steel plate sewn into his nether garments at a point just in front of and below the left nipple, obviously with the intention of protecting his heart; fortunately, however, the steel plate had worked its way downwards and was struck by a Mauser bullet as it lay over the stomach. In this case, instead of the projectile tunnelling out a small hole through the man's body and travelling far on into the country beyond him, it used up the whole of its energy as destructive work done partly upon itself and partly upon the steel plate and a large area of skin and subcutaneous tissues.

Two bullets of different calibres but possessing equal energies do not transmit, in the absence of deformation, equal quantities of energy to equal areas of impact; the larger bullet experiences more difficulty in perforation, and may even stop inside the body, expending therein the whole of its energy, while the projectile of more reduced calibre, having done but a small amount of work within the body, emerges from it and continues its course. Hence it will be seen that if we wish to expend more energy upon the objective, in other words, increase the " stopping " power of a bullet without reverting to the old large-bore bullets, we must either diminish the pitch of the helix and so lessen the bullet's stability that the slightest shock will engender a rotation about a short axis, and thus offer to the resisting tissues an increased area of disturbance, or else we must adopt less rigid and more easily deformable projectiles which, after penetration, will flatten out, thus suddenly offering a greatly increased surface of impact.

The Russian Mossine bullet, which has a penetrative energy of 3,304 ft. lbs. per inch of circumference, has been known to

TABLE IV.

Showing Comparative Power of Perforation of Bullets.

	Bullet.	Weight in Grs.	Velocity in Ft. Secs.	Diameter in Ins.	Perforation in Ft.	Medium.
1.	Mossine	310	2035	0 278	39,600·00	Air.
2.	Mannlicher	162	2395	0·315	23,400·00	,,
3.	Springfield	500	1301	0 450	22,500·00	,,
4.	Martini-Henry	480	1315	0 450	21,900 00	,,
5.	Lebel	216	2073	0·322	20,100·00	,,
6.	Remington	400	1380	0·440	19,800·00	,,
7.	Lee Straight-Pull ...	112	2489	0 243	18 900 00	,,
8.	Vetterli	310	1430	0·408	17,400 00	,,
9.	Express	1882	1450	1·052	15,600·00	,,
10.	Express	480	1780	0·577	13,800 00	,,
11.	Winchester	45	1137	0·220	8,400 00	,,
12.	Lee-Metford hard nose ...	215	2008	0·311	30 00	Bone, cancellous
13.	Remington, hard nose ..	409	1380	0·440	20·00	,, ,,
14.	Lee-Metford, hollow nose	200	2100	0 311	19 00	,, ,,
15.	Lee-Metford, hard nose...	215	2008	0 311	18 00	Water.
16.	Remington, soft nose ..	400	1400	0·440	17 00	Bone, cancellous.
17.	Lee-Metford, soft nose ..	200	2100	0 311	16·00	Muscle.
18.	Remington, hard nose ...	409	1380	0·440	15·00	,,
19.	Remington, soft nose ...	400	1400	0 440	14·00	,,
20.	Lee-Metford, hollow nose	200	2100	0·311	8 00	,,
21.	Lee-Metford, hollow nose	200	2100	0 311	6·00	Water.
22.	Lee-Metford, hollow nose	200	2100	0 311	4·58	Pine, with grain.
23.	Remington, hard nose ...	409	1380	0 440	3·33	,, ,,
24.	Lee-Metford, hard nose...	215	2008	0 311	2 50	Pine, against grain.
25.	Remington, hard nose ...	409	1380	0 440	1·83	,, ,,
26.	Lee-Metford, soft nose ...	200	2100	0·311	1·50	Pine, with grain.
27.	Lee-Metford, soft nose ...	200	2100	0 311	1·25	Pine, against grain
28.	Lee-Metford, hollow nose	200	2100	0 311	1·22	Sand, dry.
29	Lee-Metford, hollow nose	200	2100	0·311	1·20	Sand, moist.
30.	Remington, soft nose ...	400	1400	0 440	1·00	Pine, with grain.
31.	Lee-Metford, hollow nose	200	2100	0·311	·99	Paper, in leaves.
32.	Lee-Metford, hard nose...	215	2008	0 311	·93	,, ,,
33	Lee-Metford, hard nose..	215	2008	0 311	·83	Bone, compact.
34.	Lee-Metford, hollow nose	200	2100	0 311	·75	Clay, moist.
35	Remington, soft nose ...	400	1400	0 440	·60	Sand, dry.
36.	Remington, soft nose ...	400	1400	0·440	·58	Sand, moist.
37.	Remington, hard nose ...	409	1380	0 440	·57	Bone, compact.
38.	Lee-Metford, soft nose ...	200	2100	0·311	·55	Paper, in leaves.
39.	Lee-Metford, hollow nose	200	2100	0 311	·50	Bone, compact.
40.	Remington, soft nose ...	400	1400	0 440	·41	,, ,,
41.	Lee-Metford, soft nose ..	200	2100	0·311	·33	,, ,,
42.	Lee-Metford, hard nose...	215	2008	0 311	·14	Lead, in slab.
43	Lee-Metford, hollow nose	200	2100	0 311	·12	,, ,,
44.	Remington, hard nose ...	215	2008	0·311	·11	,, ,,
45.	Remington, hard nose ...	409	1380	0 400	·10	Copper, in sheets.
46.	Lee-Metford, hollow nose	200	2100	0·311	0·8	,, ,,
47.	Remington, soft nose ...	400	1400	0·440	0·6	,, ,,
48.	Lee-Metford, hard nose...	215	2008	0·311	0·2	Steel, in plates.
49.	Remington, soft nose ..	400	1400	0·440	0·1	,, ,,

perforate seven men at a range of 600 metres. In some exhaustive experiments made in France with the Lebel bullet, which has a penetrative energy per inch of circumference of 2,068 ft. lbs., upon human cadavers placed in series, it was found that:—

At 300 metres four men were perforated, the bullet lying in the fifth.

At 500 metres three men were perforated, the bullet lying in the fourth.

At 1,000 metres two men were perforated, the bullet lying in the third.

At 1,700 metres one man was perforated, the bullet lying in the second.

The penetrative energy of the Martini-Henry and Lee-Metford bullets is respectively 1,373 ft. lbs. and 2,004 ft. lbs. per inch of circumference.[1]

Heat phenomena due to impact with the tissues are very slight. If a modern bullet be fired at a bag of gunpowder backed by a steel plate, it fails to ignite it. On the other hand, heating of the projectile by friction with the rifle and contact with the enkindled gases is considerable, being above the boiling point of water, and quite sufficient to effectually sterilise it. The spores of anthrax, however, smeared on the surface of revolver bullets have been known to inoculate susceptible animals when these bullets were fired into them.

An "expansive" bullet is one which deforms readily during the perforation of moderately resisting structures, such, for instance, as the soft tissues of the human body. The word *expansive* is unfortunate, there being no real expansion, but merely an enlargement of one diameter at the expense of another; *deformative,* if one may coin the word, would surely be better. All lead bullets are deformative and mushroom during the perforation of moderately resisting structures, that is, the fore part of the bullet first meeting with resistance is temporarily checked, and the after part continuing its course telescopes into it, bulging it out laterally. Hence a bullet with a short diameter of 0.450 inch may be readily converted into one with a diameter of one inch. In sheathed bullets this deformation is not so readily brought about unless the mantle be weakened at certain points; this may be done by making the apex hollow as in the Mark IV., by longitudinal splits as in Jeffrey's sporting bullet, or by removing the sheath altogether from the apex as in the soft-nosed bullet. In this way the posterior rigid portion of the bullet is forced into the partially arrested weakened anterior part, and the sheath becoming split longitudinally, opens out like the petals of a flower, and with rapidly revolving blades, it cuts and tears its way through the tissues, producing the most terrible injuries.

[1] Let P.W.V.D. represent the penetrative energy, weight, velocity, and diameter of the projectile respectively, then $P = \frac{W V^2}{2 g \pi D}$

Deformations of the projectile may be classed as:—

1. Torsions.
2. Shears.
3. Flexures.
4. Crushings.
    - *a.* Lateral—flattening.
    - *b.* Antero-posterior—mushrooming.
5. Lacerations.
6. Fragmentations.
7. Dislocations.
    - *a.* Partial.
    - *b.* Complete.

Separation of mantle and core is by no means uncommon in the use of bullets whose sheath has been purposely weakened at one or other point. Sometimes the sheath is left behind in the barrel of the rifle, with the consequence that when the next round is fired the bullet jambs and the rifle bursts; more frequently, however, the sheath and nucleus part company outside the rifle. At Modder River the writer picked up three empty sheaths and one free nucleus. Dislocation of the nucleus from the sheath has been known to occur within the body, the nucleus passing out at one point and the sheath at another, or the former emerges leaving the latter behind. When an apparently straightforward gunshot wound festers and refuses to heal, the surgeon should bear in mind the possibility of such a separation and the use of the "X" rays will doubtless show that the entire bullet has not passed out. When using hollow-nosed and split bullets for sporting purposes the writer came across many instances of the disassociation of core and mantle and he possesses a piece of rhinoceros hide in which are firmly embedded, about three inches apart, two pieces of the sheath of a hollow-nosed bullet which had entered the animal's leg and broken up whilst traversing the bone. The nucleus, by reason of its greater momentum, had passed out, the fragments of the sheath remaining fixed in the hide.

WE now turn to a consideration of the reciprocal action and reaction between the projectile and the tissues. In traversing the several and diversified body-tissues with their very different cohesive powers the bullet meets with some, such as the solid, which vigorously resist disruption, and yet again others, such as the semi-liquid which, in virtue of the exceeding mobility of their molecules, offer but little opposition. Conversely these different tissues vary in their mode of reacting upon the projectile, the softer and more pliable being less liable to cause deformations of it than those which are harder and more rigid. Now this mechanism of the reciprocal action between the bullet and tissues is merely one of force transmission, the work done by the former being exactly equal to the force of cohesion which held these tissues together plus the energy which the projectile has communicated to them, for not only does the projectile destroy cohesion, it animates the dissociated particles, converting them into secondary projectiles.

When a bullet strikes a solid or liquid body, a series of molecular shocks radiate conewise from the point of impact to the molecules on the opposite side, these molecules then swing back and in this way the whole series is set oscillating. If the shock of impact be intense, molecules of the series farthest from the point of impact part company and fly off, thus explaining the loss of substance which occurs in the inner table around the orifice of entrance and in the outer table around the orifice of emergence in gunshot wounds of the skull.

When the tissue-molecules offer great resistance to displacement in the projectile's line of direction, they become displaced in the form of a concentric wave which spreads excentrically, secondary waves following in its wake. To these waves must be attributed the presence of radiating fractures in communication with the bullet aperture in osseous tissue.

In perforating the tissues of an animal the projectile acts not only like a hammer, driving particles in front of it, and like a wedge, displacing them laterally, but like a gimlet, communicating a part of its rotary motion to them and hurling them into the surrounding tissues like drops of water off a mop. These secondary projectiles, endowed with energy, cleave their way through and act upon the tissues in precisely the same way as the primary projectile; in this manner an organ may have its cohesion so shattered as to be completely disintegrated.

When a projectile penetrates a closed receptacle filled with an incompressible fluid, it operates as the piston of a hydraulic pump, raising the pressure throughout the whole contents. The only part of the human body in which such hydraulic action can take place is the cranium, though here the specific effects are masked by hydrodynamic phenomena. If only hydraulic action existed, an augmentation of capacity exactly equal to the volume of the bullet would occur, whereas this augmentation may be five hundred times the volume of the bullet.

There is no doubt but that a pressure suddenly applied to unconfined liquids and gases is transmitted through them; for example, a few ounces of nitro-glycerine placed in the open upon the surface of a rock of several tons weight when exploded will shatter it. In somewhat a similar way when a bullet comes into contact with fluids, effects may be produced at a considerable distance from the point of impact. The following experiment made in 1902 by the writer when at Simon's Town illustrates this transference of shock to a distance.

A large board 4½ feet in diameter was weighted on its under surface with lead sinkers. To the upper surface were fastened down fifty frogs by means of pieces of tape passed round their shoulder and hip girdles in such a way that the centres of their heads were at the following distances from the centre of the board :—

1 inch from centre	2 frogs	13 inches from centre	2 frogs
2 inches ,, ,, ...	2 ,,	14 ,, ,, ,, ...	2 ,,
3 ,, ,, ,, ...	2 ,,	15 ,, ,, ,, ...	2 ,,
4 ,, ,, ,, ...	4 ,,	16 ,, ,, ,, ...	2 ,,
5 ,, ,, ,, ...	4 ,,	17 ,, ,, ,, ...	1 frog
6 ,, ,, ,, ...	3 ,,	18 ,, ,, ,, ...	1 ,,
7 ,, ,, ,, ...	3 ,,	19 ,, ,, ,, ...	1 ,,
8 ,, ,, ,, ...	3 ,,	20 ,, ,, ,, ...	1 ,,
9 ,, ,, ,, ...	3 ,,	21 ,, ,, ,, ...	1 ,,
10 ,, ,, ,, ...	3 ,,	22 ,, ,, ,, ...	1 ,,
11 ,, ,, ,, ...	2 ,,	23 ,, ,, ,, ...	1 ,,
12 ,, ,, ,, ...	2 ,,	24 ,, ,, ,, ...	2 frogs

The whole board was then sunk under water to a depth of one foot and a 0.303-inch bullet was fired through its centre from a distance of four feet and at an incident angle of 90 degrees to the surface of the water through the centre of the board. In this way the bullet was made to pass through the centre of the circles of frogs without coming into direct contact with them. The board was then removed from the water and the animals examined.

The ten frogs up to the 4-inch circle were dead; apparently having been killed instantaneously by the concussion; the first three were torn and lacerated and their smaller bones were found to be extensively broken; the remaining seven frogs had no visible lesion.

Of the seven frogs on the fifth and sixth circles all reacted reflexly to stimuli, but were stupefied and unconscious; at the end of the day, that is in nine hours, four of them were dead and after twenty-four hours the remaining three had succumbed.

On the seventh circle the frogs responded to stimuli, though stupefied and partially unconscious; in twenty-four hours two of them were dead and one still living; this latter died after thirty hours.

On the eighth and ninth circles the frogs, though at first listless and temporarily paralysed, made voluntary movements after half an hour; they were then placed on their backs, and soon succeeded in righting themselves, and hopped away.

On the eleventh to the fourteenth circles the eight frogs were dazed, but when placed on their backs righted themselves in from two to fifteen minutes, and made efforts to escape.

All the remaining animals, from the fifteenth to the twenty-fourth circles, were lively and unharmed, hopping away directly their restraining bonds were cut.

This experiment was repeated, using small glass bulbs in place of the frogs. The results obtained were much the same. Up to the eight-inch circle the bulbs were invariably broken, between the eight-inch and fourteen-inch circles they were more frequently uninjured than broken, and beyond a fourteen-inch circle were never broken.

It is a well-known fact that if high-velocity bullets be fired through metal vessels containing water the vessels are bent and shattered in every direction quite irrespective of the fact of being closed or open. Portions of the vessel may be hurled backwards towards the firer, proving that the pressure is applied more or less simultaneously and equally at all points. This occurs even with solid structures; for instance, when a bag of marbles is fired at the marbles are scattered not only forwards but sideways and backwards.

A vacuum is produced behind a high-velocity projectile in traversing any medium. The practical effects of this vacuum are many, and will be referred to later on, here only one will be alluded to, and that is the power the bullet possesses of dragging substances into a wound after it. A large Chow dog was shot with a 0.303-inch bullet at a distance of ten feet from the muzzle. The bullet entered the back, passing out at the chest. On subsequently dissecting the animal, the little wad which separates the strands of cordite from the base of the bullet, was found embedded in the substance of the muscles lying in the hollow of the shoulder-blade, and must, therefore, have penetrated the skin, subcutaneous tissues, muscles, and even the shoulder-bone itself, having been sucked in, as it were, by the vacuum behind the base of the bullet.

Now, during the act of perforating liquid or plastic media, it is the formation of this vacuum that allows of the apparent expansion of the whole liquid or semi-liquid mass consequent upon the projectile's outward lateral impulsions. As soon as the molecules, thrust aside by the advancing conoid of the bullet, have exhausted their energy, they come to a momentary rest, and are then forced back by atmospheric pressure into the path of the bullet, where collision with returning molecules from the opposite side occasions a recoil, followed by fresh lateral expansions and the formation of secondary vacua. Thus are determined a series of undulatory movements of decreasing intensity until a state of repose is reached.

Hydraulic pressure is exerted in equal intensity in all directions, whereas hydro-dynamic pressure is especially marked in the line of direction of the projectile. Hydro-dynamic phenomena decrease with the bullet's range owing to diminution of energy imparted to the liquid molecules. Hydraulic phenomena, on the other hand, are independent of range, provided, of course, that the bullet retains sufficient energy to effect complete penetration.

In connection with the recent war there was a good deal of hard swearing on the subject of explosive bullets. Now, an explosive bullet is nothing more nor less than a miniature shell. Such a bullet is excavated and the cavity filled with an explosive and detonator; on impact with a resisting body an explosion occurs and the bullet is shivered into innumerable fragments, which, together with the evolved gases flying excentrically from the focus of explosion, produce large cavernous wounds. General Jacobs' Forsyth Swedge shell, adapted for sixteen, twelve, and ten-bore rifles, is the best example of a bullet of this nature, which is, of course, only used for sporting purposes, and was never used in the recent war.

The so-called explosive effects of hard-nosed bullets result from a modification either of the configuration or of the motion of the projectile. To the various eccentricities of flight, such as the "spinning-top," "hour-glass," and "pirouetting" motions of the projectile, must be attributed a considerable percentage of these peculiar traumatisms hitherto erroneously dubbed "explosive."

The loss of energy on the part of the projectile in its passage through the tissues is contingent upon two factors—*time of contact* and *surface of contact*. Surface of contact consists of surface of *impingement* or the area of the section of the projectile parallel to the plane struck, and *surface of friction*, or the surface area of the projectile less the surface of its base. Now, at short ranges the surface of impingement and time of contact are so small in amount that the damage done to the tissues, that is to say the energy imparted to them, is reduced to a minimum. The time of contact of a modern bullet in traversing the average human chest is about the one-three-thousandth of a second, and in traversing a forearm from before backwards, only the one-seventeenth thousandth of a second.

There now only remains to be considered the action of the projectile upon particular parts of the body.

We will deal first with the *skin*. Every surgeon and every big-game shooter is familiar with the remarkable toughness of the skin of man and other vertebrates. An instance is quoted by Sir T. Longmore, in which a whole railway train, including an engine weighing thirty-two tons, passed over a man while he was lying across the rails. On examining the body afterwards there was no wound of the skin, which was absolutely entire, but on opening the abdomen it was found that all the muscles were cut through, one kidney was cut in half, the large and small intestines were torn through and detached, and the body of the third lumbar vertebra was crushed to powder. In fact, the man was actually cut in half but the continuity of his skin prevented this fact being discovered until a *post mortem* examination revealed the state of affairs.

The entrance and exit apertures of modern bullet wounds deserve special attention. Surrounding the orifice of ingress, which is circular and smaller in diameter than the projectile, is a whitish rim, visible at the extreme brink of the little depression and due to the removal by friction of superficial layers of the skin. From this orifice radiate minute fissures, and, if the introverted sectors, of which these fissures form the radii, be carefully examined, it will be found that their tips are absent. The size of the entrance aperture increases with the range and also with the degree of laxity of the skin. Bruising around the entrance aperture is conspicuous by its absence at moderately short ranges, but is evident at the longer ranges and at extreme distances it may be very extensive without, however, there being any solution of continuity of the skin. The bullet track is usually the shortest distance between the orifices of entrance and exit; its transverse diameter as a rule is much smaller than that of the projectile.

The aperture of egress is equal to, or, may be, slightly exceeds that of ingress, its sectors are everted and show no loss of substance except in the case of the very highest velocities. The entrance aperture is occasionally multiple, the exit aperture frequently so.

The *bones* may have sufficient rigidity to withstand the shock and compel the whole of the work to be thrown into the projectile, arresting or changing its motion, or altering its form. This was frequently the case in the days of spherical bullets or of elongated bullets with low velocity, but is quite the exception in modern warfare except in the case of ricochetted or spent bullets. The "flat" and "square" bones and the extremities of the "long" bones are neatly perforated; the shafts of the bones may be tunnelled, but are more frequently fractured; in the latter case, when velocity is very high, minute comminution occurs with the wide dispersal of numerous splinterettes; when the velocity is low the splinters are larger, less numerous, and lie closer to the fracture.

Rotation of the bullet plays a most important part in the perforation of bone. There is an actual, though perhaps slight, loss of substance in the form of bone-dust which may be carried to a distance through the tissues. This bone-dust is caused, not so much by the crushing action of the bullet consequent on its motion of translation, as by its grinding action due to the motion of rotation about a long axis. If a number of bullets from a battle-field or rifle-range be examined, it will be noticed that in some the scoriæ are almost parallel to the grooving, these are bullets which have struck the ground at a short range, in others the pitch of the spiral marked on the sheath of the bullet by friction with ground has a less acute inclination to the natural grooving caused by the rifling, these are the ones that have struck the ground at yet longer ranges. Finally, upon the surface of bullets that have been suddenly arrested within the substance of resisting structures are marks and scratches, which are practically circles in planes at right angles to the long axis of the bullet. This shows that the bullet spins faster relatively to its rate of progress. For instance, if the 0·303-inch bullet makes one turn in the first ten inches of its flight, it does not continue to turn in this same spiral for the rest of it. Further on in its course it may be only making one turn in six inches and yet get further on; when its forward motion of translation has all been destroyed it remains within the tissues of the body, making one turn in 0 inches; in other words, it is rotating rapidly in one spot.

In some further experiments made by the writer 0.303-inch bullets were fired at the ribs and vertebræ of a stranded whale. It was found, on examining the bullet track in the bone, that for the first few inches from the entrance no bone-dust was to be seen. At a depth of about five inches bone-dust became visible and increased in quantity as the distance from the entrance aperture became greater, the maximum amount being found immediately around the sides of the bullet, but none in front of it. On withdrawing the missile the longitudinal grooves were found to be filled with compressed bone-dust of the fineness of flour. These facts prove conclusively that the production of this bone-dust is due solely to the rotary action of the bullet, and has nothing to do with its movements of translation.

In considering the effects of bullets upon bones, their greater fragility with increase of age has to be reckoned with. In some experiments made by an American surgeon with the Lee Straight-Pull rifle in 1907, it was found that when a six-millimetre bullet, weighing 112 grs., and with a velocity of 2,560 ft. secs., was fired at the head of an old ox and a young calf, respectively, the cranium of the former was completely broken up and the mantled bullet was lacerated, the head of the calf was neatly perforated, the bones were not fractured, and the bullet did not suffer in shape.

Multiple exits in the skin sometimes occur from bone fragments, which, having acquired sufficient velocity from the bullet, force their way out of the body. In a jackal, killed by the writer with a 0.303-inch bullet of the hollow-nosed variety, as many as fifteen exit wounds were counted in the skin at the back of the neck; the bullet having entered the left thigh by a minute hole, had emerged just behind the junction of the head and neck. Some of these exit apertures were doubtless caused by fragments of the bullet, but the majority of them were due to fragments of the left femur, pelvis, and vertebræ having been forced through the skin.

The ratio of the diameter of the bullet to the diameter of the objective, at the point struck, has also to be considered. For example, a 0.303-inch bullet will neatly perforate the extremity of the human shin-bone, but a 0.450-inch bullet has been known to knock off both the legs of a deer at the knee joint, leaving the upper sides of the joints as though severed with a knife.

The amount of stress in the bone is of the utmost importance. Thus, in a soldier on the march, the leg-bone on one side of his body may be subjected to a straining force of about two hundred pounds, while the other is in an indifferent condition as regards stress. In the former instance, much energy would be expended by the bullet, and consequently much damage inflicted upon the bone. In the latter case the bullet parts with but little energy, and perpetrates less mischief.

Many instances are on record of partial or complete recovery after bullet perforations of both cerebral hemispheres. As the projectile enters the cranial space, intracranial pressure rises and cerebro-spinal fluid and blood are expelled through the various circumferential foramina. The following experiment illustrates this in a forcible manner. A human skull was taken in which had been carefully blocked up with wax every aperture except the large one through which the brain and spinal cord communicate, the skull was then inverted and filled with water through this opening. On firing a hollow-nosed 0.303-inch bullet through the centre of the skull a column of water was forced out to a height of five feet.

In gunshot wounds of the head, brain matter may protrude, not only from the egress, but also from the ingress aperture. The writer remembers being much impressed by seeing a Highlander who had walked four miles after the battle of Magersfontein, with cerebral substance oozing from entrance and exit wounds in the head, caused by a Mauser bullet. Two months later this man was still living, and apparently doing well. Want of time precludes me from quoting more than an isolated example from among several remarkable instances of recovery following bullet injuries of the brain. Doubtless much of the wonderful anabolic powers exhibited in these latter-day bullet wounds is attributable to the ballistic qualities and humaneness of the small-bore projectile. Nevertheless, these marvellous recuperations would not have been so much in evidence were it not for the extreme skill and untiring care displayed by modern military surgeons.

After the brief compression of the brain by the projectile, there is a subsequent increase of bulk, due to swelling and effusion of fluid, which aggravates the protrusion of cerebral matter through the bullet orifices. Brain matter seldom, if ever, protrudes through an orifice of ingress when death is immediate.

Lateral pressures of the brain are liable, though the heart continues to beat, to cause death from mechanical lesion of the respiratory centre, hence, in certain rare cases of gunshot wounds of the head, the fact is worth bearing in mind that a timely artificial respiration might assist towards recovery.

Concussion of the brain without compression may be produced by glancing blows against the vault of the cranium. In such circumstances the most favourable prognosis may usually be given. The writer once had a most curious, though disappointing, experience in this connection. When on a shooting expedition in East Africa he came across a herd of water buck, and, selecting the largest one, fired at it. The range was about two hundred yards and the bullet was a 0.303-inch hollow-nose. The herd stampeded, including the buck aimed at, but another buck just behind fell without a sound or struggle, apparently stone dead. Walking leisurely up to it, the writer put his rifle on the ground, and was proceeding to examine the animal, when it suddenly recovered consciousness, gained an upright position, and staggered off into the bush, never to be seen again. The blood marks on the ground clearly indicated that the beast had been struck somewhere in the nape of the neck, and it is more than probable that the bullet grazed, but did not penetrate the bony casing of the brain, thereby transmitting sufficient shock to its contents to produce temporary oblivion.

The dense, inelastic, fibrous membranes of the brain play a most important part in gunshot injuries of the head. The *dura mater*, a tough, cloth-like covering of the brain, separating it from the skull, arrests much of the bone *débris* that would otherwise be forced by the projectile into the substance of the brain; and the tent-like covering of the lesser brain shields that organ from a large part of the shock delivered to the big brain when the latter is struck. Fracture of the bones forming the eye-socket, together with dislocation of the eyeball, is not uncommon after bullet perforations of the fore-brain.

The following experiments were made with a view to illustrate the effects of different bullets upon the human head. These heads are now preserved in spirit, and may be seen by anyone who takes the trouble to pay a visit to the Haslar Hospital Museum. In each case the head was so placed that the line of fire coincided with a line passing from the centre of the forehead to the junction of the skin of the neck with the scalp. The range in every case was six feet.

Head No. 1.

Horizontal circumference ...	21·2 inches.
Antero-posterior diameter	7·4 ,,
Distance from chin to vertex	9·4 ,,
Lateral diameter	5·7 ,,
Weight of head before firing	137·000 ounces.
,, ,, after firing	136·500 ,,
Loss of weight caused by bullet...	0·500 ,,
Relative loss of weight	0·0036
Bullet ...	Mauser, hard-nosed.
Diameter of bullet ...	0·276-inch.
Weight of bullet	172·0 grains.
Velocity of bullet ...	2200·0 feet-seconds.
Energy of bullet	1846·0 foot-pounds.
Value of $\frac{D^2}{W}$	2·50

The entrance aperture was 0.05 inch in diameter. The exit measured 0.12-inch by 0.06-inch; its edges were slightly turned in, and a small quantity of brain matter exuded from it. The lower jaw, vault and face bones were intact, with the exception of the already mentioned apertures in the frontal and occipital bones. After the bullet had perforated the head it underwent a further perforation of 27 inches of water and 8 inches of soft fir wood, and suffered no deformation.

Head No. 2.

Horizontal circumference ...	21·0 inches.
Antero-posterior diameter...	7·2 ,,
Distance from chin to vertex	9·2 ,,
Lateral diameter	5·4 ,,
Weight of head before firing	130·000 ounces.
,, ,, after firing	93·250 ,,
Loss of weight caused by bullet...	36·750 ,,
Relative loss of weight	0·2857
Bullet ...	Mauser, soft-nosed.
Diameter of bullet ...	0·276-inch.
Weight of bullet	172·0 grains.
Velocity of bullet ...	2200·0 feet-seconds.
Energy of bullet	1846·0 foot-pounds.
Value of $\frac{D^2}{W}$	2·50

Both entrance and exit apertures were indeterminate, being directly continuous with large lacerations extending throughout the scalp. Some of these rents were seven and eight inches long; sixteen fragments of bone, together weighing four and a half ounces, were found hanging to the scalp by shreds of periosteum. The lower jaw was intact, but all the bones of the vault, base, and upper part of the face were smashed to fragments. The projectile itself broke up into several small pieces in its passage through the brain, and some of these, emerging from the skull, underwent a further penetration of twenty-five inches of water and 0.25 inches of soft fir wood backing.

Head No. 3.

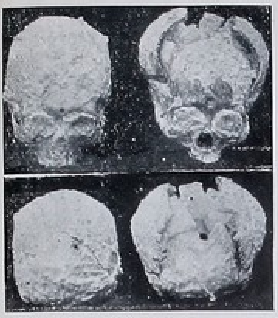
Horizontal circumference	21·7 inches.
Antero-posterior diameter	7·4 ,,
Distance from chin to vertex	9·3 ,,
Lateral diameter	5·6 ,,
Weight of head before firing	158·000 ounces.
,, ,, after firing	117·000 ,,
Loss of weight caused by bullet...	41·000 ,,
Relative loss of weight	0·2631
Bullet	Martini-Henry.
Diameter of bullet	0·450-inch.
Weight of bullet	480·0 grains.
Velocity of bullet	1315·0 feet-seconds.
Energy of bullet	1841·0 foot-pounds.
Value of $\frac{D^2}{W}$	2·950.

The entrance and exit apertures were indeterminate, being connected with long rents extending throughout the scalp. Eight fragments of bone, together weighing five ounces, were found hanging by periosteum to the collapsed head. The scalp was divided up into four large triangular flaps and one median leaf-shaped one; the longest of these measured eight inches. Some of these flaps included the whole thickness of the scalp, bone, and membranes. The base of the skull alone was fractured into over forty fragments; all the face bones were broken up, but the lower jaw unhurt.

The bullet mushroomed, presumably inside the skull, and after emerging from it underwent a further perforation of twenty inches of water.

Head No. 4.

Horizontal circumference	22·7 inches.
Antero-posterior diameter	7·5 ,,
Distance from chin to vertex	10·0 ,,
Lateral diameter	6·0 ,,
Weight of head before firing	173·000 ounces.
,, ,, after firing	129·500 ,,
Loss of weight caused by bullet	43·5000 ,,
Relative loss of weight	0·2518.
Bullet	Snider.
Diameter of bullet	0·577-inch.
Weight of bullet	480·0 grains.
Velocity of bullet	1240·0 feet-seconds.
Energy of bullet	1637·0 foot-pounds.
Value of $\frac{D}{W}$	4·850.



Nos. 1 and 2.

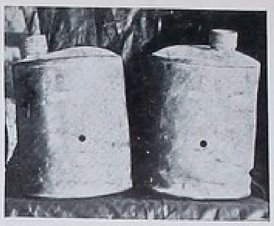
Skulls filled with wax to show comparative effects of the hard and soft nosed bullets. The two left-hand skulls show effect of hard nose. The two right-hand skulls effect of soft nose.

No. 3.

Monkey shot in East Africa with a 0·303-inch hollow nosed bullet. Entrance lower front of neck. Exit right iliac region. Note the protrusion of large and small intestines through exit aperture.

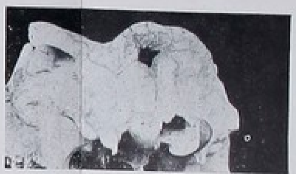
No. 4.

Exit aperture in skull of a 0·45-inch bullet.



No. 6.

Hydraulic effect of bullet. (See also text.)



No. 8.

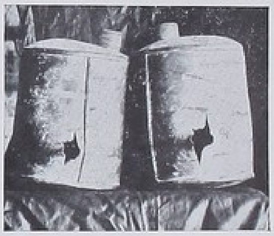
Entrance aperture of a hollow-nosed 0·303-inch bullet at the back of the skull of a hippopotamus shot in East Africa. Note the radiating fractures.

No. 10.

Filipino skulls showing shell injuries.

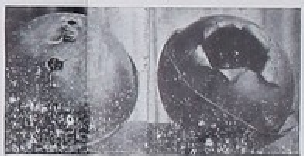
No. 5.

Skull showing exit of a Springfield bullet.



No. 7.

Hydrodynamic effect of bullet (Explanation in text.)



No. 9.

Showing entrance and exit apertures of a 0·303-inch bullet.

No. 11.

Showing a Krag-Jorgenson bullet injury of the skull. Entrance in back of skull, exit at inner side of right eye.

No. 13.

Showing entrance aperture of a hard-nosed Mauser bullet.

No. 14.

Showing exit aperture of a hard-nosed Mauser bullet.

No. 15.

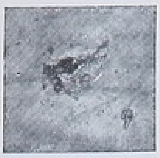
Showing effects of a soft-nosed Mauser bullet. Compare with 13 and 14.

No. 17.

Showing effects of the old Snider bullet.

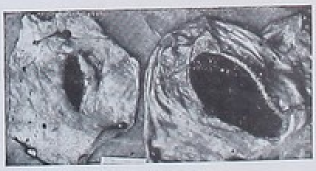
No. 18.

Showing entrance wound of 0·303-inch bullet in anterior wall of an empty stomach.



No. 19.

Showing exit wound of 0·303 inch bullet in posterior wall of an empty stomach.



No. 20.

Showing entrance and exit wounds of 0·303-inch bullet in a stomach.

No. 16.

Showing effects of Martini-Henry bullet.

J. J. K. & Co., Limited, London.

The entrance and exit apertures were indeterminate, being continuous with large rents in the scalp varying from three to nine inches in length; six loose fragments of bone, weighing 1.25 ounces, were suspended by shreds of periosteum from the completely disorganised cranium. All the bones of the base, vault, and face, were broken up into small pieces. The lower jaw was fractured opposite the right canine tooth, the frontal bone alone accounted for sixteen pieces; cerebral fluid was forced out of the nostrils and out of the ears, and both eyes were partially proptosed. The further penetration of the fragments of the bullet was inappreciable. One or two small fragments were embedded to a depth of 0.1 inch to 0.2 inch in the fir wood forming the backing. The majority, however, still remained scattered throughout the remains of the skull.

Organs like the stomach, bladder, and intestines are grievously injured and their contents scattered far and wide if fluid be present in any appreciable quantity. If empty, however, minute apertures are produced, which close immediately after the passage of the bullet, and heal by first intention, thus preventing any leakage of the contents and subsequent peritoneal infection. For this reason a soldier wounded in the stomach after a full meal would have a much smaller chance of recovery than one wounded whilst in a fasting condition. A pig's stomach was fired at with a 0.303-inch bullet at a range of ten yards. The apertures of entrance and exit were of equal size, scarcely measuring 0.20-inch across. A second pig's stomach, partially filled with fluid, was then fired at under similar circumstances, the aperture of entrance measured 0.20-inch diameter; the aperture of exit was 0.50-inch by 0.80-inch diameter. Experiments with the bladder and intestines gave similar results.

The possibility of more than one coil of gut having been perforated must be borne in mind when dealing with bullet lesions of the alimentary canal.

Similar experiments made upon the heart of the sheep and bullock prove that bullet wounds of the ventricular cavities during a state of complete contraction—artificially produced outside the body—show small entrance and exit apertures; on the other hand, wounds of the ventricles when full and expanded show ruptures and lacerations of muscles and valves.

Modern bullet wounds of the lungs as a rule heal quickly and easily. It is obvious that a cubic inch of lung tissue at the end of inspiration contains a smaller proportion of solid and liquid matter than at the end of expiration, when the walls of the air cells are approximated. Practically this may be of but little interest; but nevertheless the fact remains that a soldier hit in his region just at the end of taking a deep breath would sustain less damage—other things being equal—than if hit at the end of expiration. Two pairs of sheep's lungs were taken; the first was forcibly inflated and the second deflated as much as possible, the wind-pipe of each being then closed. After firing a Lee-Metford bullet through them it was found that the air-distended lungs had suffered less than the others.

The lubricating wax with which some bullets are coated acts chemically upon the copper in the sheathing to produce a subacetate of copper. Now only the minutest traces of such verdigris could possibly gain access to any bullet wound, and it is not likely that any poisonous effects would follow the application of so minute a quantity of this salt. The brass-sheathed Remington bullet used by the Filipinos in the American-Filipino campaign undoubtedly caused a higher percentage of cases of tetanus amongst the American soldiers than did the neat little Mauser bullet with which the Filipinos were also armed. However, the tetanus was probably due rather to the greater smashing and lacerating effects of the clumsy 0.440-inch Remington bullet than to any difference in composition of their respective sheaths. Bullets containing a high percentage of steel in their sheathing rust more easily in wounds than the cupro-nickel sheathed ones. The power of the bullet at close ranges to drag the wad of the cartridge into the depths of the tissues and its liability at medium and long ranges to push or draw in shreds of clothing, are factors not to be overlooked in connection with deep suppuration of the bullet track.

Owing to the extremely short contact-time of the modern projectile — about one-eight-thousandth of a second — pain, which at first sight we might expect to accompany or follow the actual perforation, is often totally absent, and in moments of extreme excitement even so large a region as the chest may be completely perforated without the victim being aware at the time of the fact. Local anæsthesia of the bullet wound, especially in the proximity of its entrance is another characteristic caused by the modern projectile.

External bleeding from bullet apertures is usually very slight. Severe internal hæmorrhage, however, is not rare, as the modern small-bore bullet bores its way through the larger blood vessels instead of pushing them aside, as did the older bullets.

The limit of small-bore projectiles with very high angular velocities must soon be reached for mechanical reasons, if, indeed, it has not already been overstepped in the 0.236-inch American bullet, which not infrequently strips inside the barrel of the rifle. Military surgeons of all nations have noted with satisfaction the general and universal tendency during the present decade towards the adoption of less malign bullets, and they will ever welcome the advent of every diminution of calibre and weight of the projectile, so long as its ballistic properties are not interfered with. Quite recently our illustrious neighbours, the Germans, have been experimenting with a new bullet called the "S" or Spitz-Geschoss, which shows every indication of causing far less dangerous wounds than their 1888 pattern Mauser bullet, with at the same time a distinct gain in ballistic value. This bullet has been lightened by 72.7 grains by paring away the anterior end so as to make it much more pointed and wedge shaped. The muzzle velocity has been increased by 810 feet-seconds, partly by this lightening of the bullet and partly by an increased chamber pressure. A comparison of the Spitze-Geschoss bullet with the Lee-Metford is shown in Table V.

Table V., showing comparison between the English Lee-Metford and the German Spitze-Geschoss Bullet.

—	Lee-Metford.	Spitze-Geschoss.
Diameter	0·303	0·315
Weight in grains	215	154
Velocity at 0 yards	2,060	2,909
,, 500 yards	1,229	1,712
,, 1,000 yards	886	1,039
Striking energy at 0 yards	2,036	2,916
,, ,, 500 yards	724	1,009
,, ,, 1,000 yards	377	871
Height of trajectory for a range of 400 yards.		
At 0 yards	0	0
At 100 ,, ...	19	8·5
,, 200 ,, ...	28	11·75
,, 300 ,, ...	22	9·0
,, 400 ,, ...	0	0

In the author's opinion much may yet be done to render modern bullets still more humane; more particularly would he urge the adoption of the following :—

1. A general lowering of calibre to at least 0.300-inch. The 0.270-inch bullet possesses excellent ballistic properties and quite sufficient stopping power for civilised warfare.
2. A projectile which is ogival and sheathed at both ends. The use of an elongated projectile, with an ogival head, having a curvature of, say, four to six calibres, and an ogival tail with curvature equal to one to two calibres, would do away with much of the vacuum effects, give increased range and stability, and disallow of any divorce between core and mantle.
3. The cannelure which exists in some bullets just above the base to be made obsolete, as it impedes flight by causing eddies and stern waves, and greatly exaggerates the bullet's hydrodynamic effects.

4. A sheath that does not easily rust, such, for instance, as our own cupro-nickel one. The sheath of the Mauser bullet, as used in the late Boer war, was composed either of an alloy of copper, nickel, and zinc, or of steel coated with cupro-nickel, and was exceedingly liable to rust, especially when lying in a wound.

In conclusion, the author confidently prognosticates that in consequence of the inevitable further evolution of the bullet towards perfection, those protracted cases of suppurating bullet wounds with which the military surgeon of to-day has not infrequently to deal will be looked upon by surgeons of the future as pathological curiosities.

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