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Return to Anatomy of Firearms.

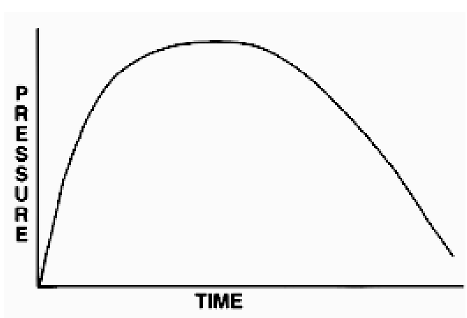
Ballistics

The term ballistics refers to the science of the travel of a projectile in flight. The flight path of a bullet includes: travel down the barrel, path through the air, and path through a target. The wounding potential of projectiles is a complex matter. (Fackler, 1996)

Internal, or initial ballistics (within the gun)

Bullets fired from a rifle will have more energy than similar bullets fired from a handgun. More powder can also be used in rifle cartridges because the bullet chambers can be designed to withstand greater pressures (70,000 psi vs. 40,000 psi for handgun chamber). Higher pressures require a bigger gun with more recoil that is slower to load and generates more heat that produces more wear on the metal. It is difficult in practice to measure the forces within a gun barrel, but the one easily measured parameter is the velocity with which the bullet exits the barrel (muzzle velocity) and this measurement will be used in examples below.

The controlled expansion of gases from burning gunpowder generates pressure (force/area). The area here is the base of the bullet (equivalent to diameter of barrel) and is a constant. Therefore, the energy transmitted to the bullet (with a given mass) will depend upon mass times force times the time interval over which the force is applied. The last of these factors is a function of barrel length. Bullet travel through a gun barrel is characterized by increasing acceleration as the expanding gases push on it, but decreasing pressure in the barrel as the gas expands. Up to a point of diminishing pressure, the longer the barrel, the greater the acceleration of the bullet. (Volgas, Stannard and Alonso, 2005)



As the bullet traverses the barrel of the gun, some minor deformation occurs, called setback deformation. This results from minor (rarely major) imperfections or variations in rifling or tool marks. The effect upon the subsequent flight path of the bullet is usually insignificant. (Jandial et al, 2008)

External ballistics (from gun to target)

The external ballistics of a bullet's path can be determined by several formulae, the simplest of which is:

Kinetic Energy (KE) = 1/2 MV^2

Velocity (V) is usually given in feet/second (fps) and mass (M) is given in pounds, derived from the weight (W) of the bullet in grains, divided by 7000 grains per pound times the acceleration of gravity (32 ft/sec) so that:

Kinetic Energy (KE) = $W(V)^2$ / (450,435) ft/lb

This is the bullet's energy as it leaves the muzzle, but the ballistic coefficient (BC) will determine the amount of KE delivered to the target as air resistance is encountered.

Forward motion of the bullet is also affected by drag (D), which is calculated as:

Drag (D) = $f(v/a)k\&pd^2v^2$

f(v/a) is a coefficient related to the ratio of the velocity of the bullet to the velocity of sound in the medium through which it travels. k is a constant for the shape of the bullet and & is a constant for yaw (deviation from linear flight). p is the density of the medium (tissue density is >800 times that of air), d is the diameter (caliber) of the bullet, and v the velocity. Thus, greater velocity, greater caliber, or denser tissue gives more drag. The degree to which a bullet is slowed by drag is called retardation (r) given by the formula:

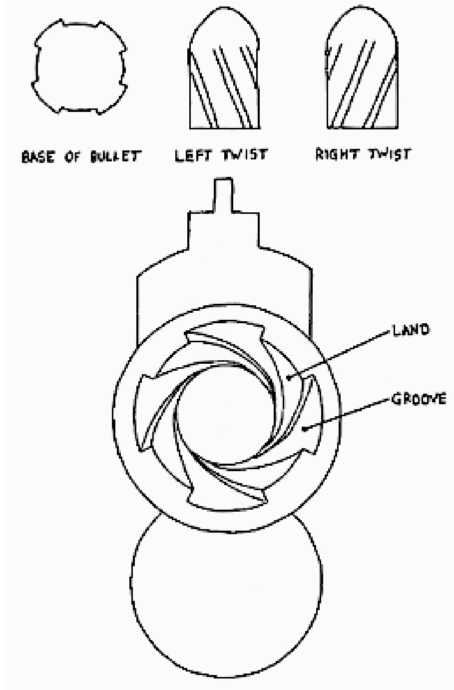
r = D / M

Drag is difficult to measure, so the Ballistic Coefficient (BC) is often used:

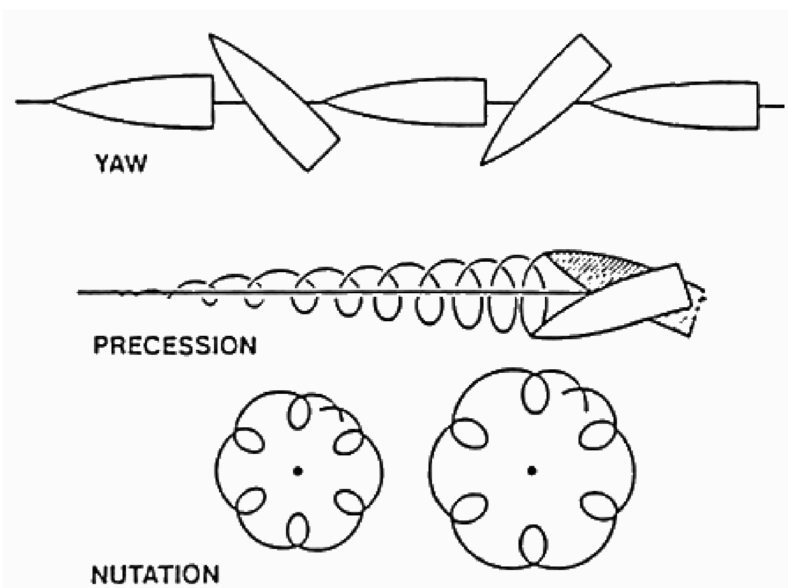
BC = SD / I

SD is the sectional density of the bullet, and I is a form factor for the bullet shape. Sectional density is calculated from the bullet mass (M) divided by the square of its diameter. The form factor value I decreases with increasing pointedness of the bullet (a sphere would have the highest I value).

Since drag (D) is a function of velocity, it can be seen that for a bullet of a given mass (M), the greater the velocity, the greater the retardation. Drag is also influenced by bullet spin. The faster the spin, the less likely a bullet will "yaw" or turn sideways and tumble in its flight path through the air. Thus, increasing the twist of the rifling from 1 in 7 will impart greater spin than the typical 1 in 12 spiral (one turn in 12 inches of barrel).



Bullets do not typically follow a straight line to the target. Rotational forces are in effect that keep the bullet off a straight axis of flight. These rotational effects are diagrammed below:



Yaw refers to the rotation of the nose of the bullet away from the line of flight. Precession refers to rotation of the bullet around the center of mass. Nutation refers to small circular movement at the bullet tip. Yaw and precession decrease as the distance of the bullet from the barrel increases.

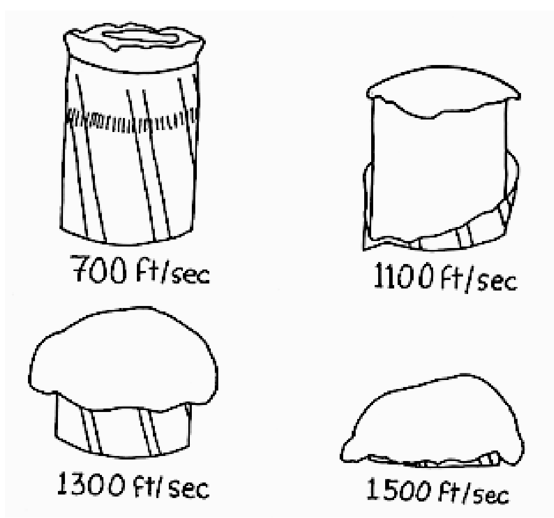
What do all these formulae mean in terms of designing cartridges and bullets? Well, given that a cartridge can be only so large to fit in a chamber, and given that the steel of the chamber can handle only so much pressure from increasing the amount of gunpowder, the kinetic energy for any given weapon is increased more easily by increasing bullet mass. Though the square of the velocity would increase

KE much more, it is practically very difficult to increase velocity, which is dependent upon the amount of gunpowder burned. There is only so much gunpowder that can burned efficiently in a cartridge. Thus, cartridges designed for hunting big game animals use very large bullets.

To reduce air resistance, the ideal bullet would be a long, heavy needle, but such a projectile would go right through the target without dispersing any of its energy. Light spheres would be retarded the greatest and release more energy, but might not get to the target. A compromise for a good aerodynamic shape is a parbolic curve with low frontal area and wind-splitting shape. The best bullet composition is lead (Pb) which is of high density and is cheap to obtain. Its disadvantages are a tendency to soften at velocities >1000 fps, causing it to smear the barrel and decrease accuracy, and >2000 fps lead tends to melt completely. Alloying the lead (Pb) with a small amount of antimony (Sb) helps, but the real answer is to interface the lead bullet with the barrel through another metal soft enough to seal the bullet in the barrel but of high melting point. Copper (Cu) works best as this "jacket" material for lead.

Terminal ballistics (hitting the target)

Yaw has a lot to do with the injury pattern of a bullet on the target, termed "terminal ballistics." A short, high velocity bullet begins to yaw more severely and rotate upon entering tissue. This causes more tissue to be displaced, increases drag, and imparts more of the KE to the target. A longer, heavier bullet might have more KE at a longer range when it hits the target, but it may penetrate so well that it exits the target with much of its KE remaining. Even a bullet with a low KE can impart significant tissue damage if it can be designed to give up all of the KE into the target, and the target is at short range (as with handguns). Despite yaw, an intact bullet that comes to rest in tissue generally has its long axis aligned along the path of the bullet track, though its final position may be either nose forward or base forward. (Jandial et al, 2008)



Bullets produce tissue damage in three ways (Adams, 1982):

1. Laceration and crushing - Tissue damage through laceration and crushing occurs along the path or "track" through the body that a projectile, or its fragments, may produce.

2. Cavitation - A "permanent" cavity is caused by the path (track) of the bullet itself

with crushing of tissue, whereas a "temporary" cavity is formed by radial stretching around the bullet track from continued acceleration of the medium (air or tissue) in the wake of the bullet, causing the wound cavity to be stretched outward. For projectiles traveling at low velocity the permanent and temporary cavities are nearly the same, but at high velocity and with bullet yaw the temporary cavity becomes larger (Maiden, 2009).

3. Shock waves - Shock waves compress the medium and travel ahead of the bullet, as well as to the sides, but these waves last only a few microseconds and do not cause profound destruction at low velocity. At high velocity, generated shock waves can reach up to 200 atmospheres of pressure. (DiMaio and Zumwalt, 1977) However, bone fracture from cavitation is an extremely rare event. (Fackler, 1996) The ballistic pressure wave from distant bullet impact can induce a concussive-like effect in humans, causing acute neurological symptoms. (Courtney and Courtney, 2007)

The mathematics of wound ballistics, in reference to yaw of unstable projectiles, has been described. The model works well for non-deformable bullets. (Peters et al, 1996)(Peters and Sebourn, 1996)

Experimental methods to demonstrate tissue damage have utilized materials with characteristics similar to human soft tissues and skin. Pigskin has been employed to provide an external layer to blocks of compounds such as ordnance gelatin or ballistic soap. Firing of bullets into these materials at various ranges is followed by direct visual inspection (cutting the block) or radiographic analysis (CT imaging) to determine the sizes and appearances of the cavity produced (Rutty, et al, 2007).

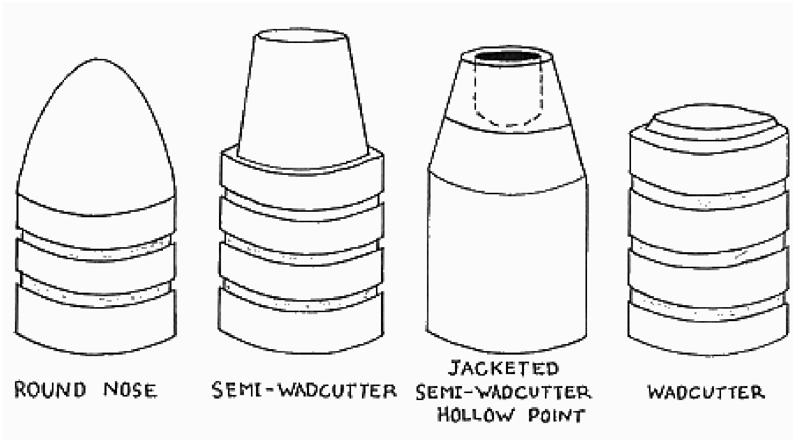
The following images illustrate bullet deformation and damage:

- **Bullet track in clay model, gross**
- **Deformed bullet recovered from shooting victim, gross**

Bullet velocity and mass will affect the nature of wounding. Velocity is classified as low (<1000 fps), medium (1000 to 2000 fps), and high (>2000 fps). (Wilson, 1977) An M-16 rifle (.223 cal) is designed to produce larger wounds with high velocity, lower mass bullets that tumble, cavitate, and release energy quickly upon striking the target. A hunting rifle (.308 cal or greater) would have a larger mass bullet to penetrate a greater depth to kill a large game animal at a longer distance.

Bullet design is important in wounding potential. The Hague Convention of 1899 (and subsequently the Geneva Convention) forbade the use of expanding, deformable bullets in wartime. Therefore, military bullets have full metal jackets around the lead core. Of course, the treaty had less to do with compliance than the fact that modern military assault rifles fire projectiles at high velocity (>2000 fps) and the bullets need to be jacketed with copper, because the lead begins to melt from heat generated at speeds >2000 fps.

Bullet shapes are diagrammed below:



The distance of the target from the muzzle plays a large role in wounding capacity, for most bullets fired from handguns have lost significant kinetic energy (KE) at 100 yards, while high-velocity military .308 rounds still have considerable KE even at 500 yards. Military and hunting rifles are designed to deliver bullets with more KE at a greater distance than are handguns and shotguns.

The type of tissue affects wounding potential, as well as the depth of penetration. (Bartlett, 2003) Specific gravity (density) and elasticity are the major tissue factors. The higher the specific gravity, the greater the damage. The greater the elasticity, the less the damage. Thus, lung tissue of low density and high elasticity is damaged less than muscle with higher density but some elasticity. Liver, spleen, and brain have no elasticity and are easily injured, as is adipose tissue. Fluid-filled organs (bladder, heart, great vessels, bowel) can burst because of pressure waves generated. A bullet striking bone may cause fragmentation of bone and/or bullet, with numerous secondary missiles formed, each producing additional wounding.

The speed at which a projectile must travel to penetrate skin is 163 fps and to break bone is 213 fps, both of which are quite low, so other factors are more important in producing damage. (Belkin, 1978)

Designing a bullet for efficient transfer of energy to a particular target is not straightforward, for targets differ. To penetrate the thick hide and tough bone of an elephant, the bullet must be pointed, of small diameter, and durable enough to resist disintegration. However, such a bullet would penetrate most human tissues like a spear, doing little more damage than a knife wound. A bullet designed to damage human tissues would need some sort of "brakes" so that all the KE was transmitted to the target.

It is easier to design features that aid deceleration of a larger, slower moving bullet in tissues than a small, high velocity bullet. Such measures include shape modifications like round (round nose), flattened (wadcutter), or cupped (hollowpoint) bullet nose. Round nose bullets provide the least braking, are usually jacketed, and are useful mostly in low velocity handguns. The wadcutter design provides the most braking from shape alone, is not jacketed, and is used in low velocity handguns (often for target practice). A semi-wadcutter design is intermediate between the round nose and wadcutter and is useful at medium velocity. Hollowpoint bullet design facilitates turning the bullet "inside out" and flattening the front, referred to as "expansion." Expansion reliably occurs only at velocities exceeding 1200 fps, so is suited only to the highest velocity handguns.

Wounding is an extremely complex situation with variables of bullet size, velocity, shape, spin, distance from muzzle to target, and nature of tissue. These factors are interrelated, and the wounding potential may be difficult to predict even under controlled test conditions. In an actual forensic case, few of the variables may be known, and it is up to the medical examiner to determine what can be known from examination of the evidence.

Blood loss depends upon the size of the wound, the number and size of blood vessels damaged, and total body blood volume. A healthy 80 kg man has a blood volume of 4800 mL, and loss of 25% of this volume leads to incapacitation through diminished cardiac output and oxygenation (Maiden, 2009).

The best approach to wound care is conservative. With simple punctures and no apparent tissue disruption, just irrigation and application of a dressing may suffice. So-called "high velocity" rounds are not necessarily more damaging because they are jacketed and the bullet is smaller in size. Variability in wounding from such rounds is potentially, but not often practically, a function of bullet yaw. A fully jacketed 7.62 mm military round creates a much smaller temporary and permanent cavity in tissue than a 7.62 mm civilian "hunting" round with a soft point tip, despite the fact that both are "high velocity" rounds. Treatment guidelines include the use of antibiotics if necessary, and debridement of devitalized tissues when greater tissue disruption is apparent. It can be difficult to determine the extent of disruption and the amount of non-viable tissue, so reassessment of more disruptive wounds left open for 48 hours can be done. In short, "treat the wound, not the weapon." (Santucci and Chang, 2004) (Fackler, 1998)

Antibiotic prophylaxis is recommended in high-velocity, shotgun, and intraarticular gunshot fractures. Bullets are not sterile and may have encountered intermediate targets such as clothing prior to entering the body. The pressure difference from atmospheric pressure to a temporary cavity through a bullet track may allow air to sweep debris inward, causing contamination of the wound. (Jandial et al, 2008) The recommendation for high-velocity gunshot or shotgun injuries is intravenous administration of at least 48 hours of a first-generation cephalosporin, with addition of gentamicin in cases of soft tissue defects or cavitary lesions. Penicillin must be added in patients with gross wound contamination. (Simpson et al, 2003) (Santucci and Chang, 2004)

Handgun Ballistics

These weapons are easily concealed but hard to aim accurately, especially in crime scenes. Most handgun shootings occur at less than 7 yards, but even so, most bullets miss their intended target (only 11% of assailants' bullets and 25% of bullets fired by police officers hit the intended target in a study by Lesce, 1984). Usually, low caliber weapons are employed in crimes because they are cheaper and lighter to carry and easier to control when shooting. Tissue destruction can be increased at any caliber by use of hollowpoint expanding bullets. Some law enforcement agencies have adopted such bullets because they are thought to have more "stopping power" at short range. Most handgun bullets, though, deliver less than 1000 ft/lb of KE. (Ragsdale, 1984)

However, there is a myth, kept alive by portrayals of shooting victims on television and in films being hurled backwards, that victims are actually "knocked down" or displaced by being struck with the force of a bullet. In fact, real gunshot victims relate that they had no immediate reaction. (Fackler, 1998) The maximum momentum transferred from different small arms projectiles, inluding large caliber rifles and shotguns, to an 80 kg body is only 0.01 to 0.18 m/s, negligible compared to the 1 to 2 m/s velocity of a pedestrian. (Karger and Knewbuehl, 1996) Incapacitation of gunshot victims is primarily a function of the area of the body wounded. Immediate incapacitation may occur with gunshot wounds to the brain and upper cervical cord. Rapid incapacitation may occur with massive bleeding from major blood vessels or the heart. (Karger, 1995)

The two major variables in handgun ballistics are diameter of the bullet and volume of gunpowder in the cartridge case. Cartridges of older design were limited by the pressures they could withstand, but advances in metallurgy have allowed doubling and tripling of the maximum pressures so that more KE can be generated.

Many different cartridges are available using different loads and bullet designs. Some of these are outlined in the table below to compare and contrast the ballistics.

Common Representative Handgun Cartridges							
Name	**Comment**	**Case Length**	**Case Diameter**	**Bullet Weight (grains)**	**Velocity (muzzle) in fps**	**Energy (muzzle) in ft lbs**	**Energy (at 100 yd) in ft-lbs**
.22 LR	for inexpensive guns, rimfire (R and A)	0.625	0.222	40	1060	100	75
.25 auto	small pocket gun (A only)	0.615	0.251	45	815	66	42
.380 auto	popular pocket auto (A only)	0.680	0.355	85	1000	189	140
9 mm para	popular military handgun (A only)	0.754	0.355	115	1155	391	241
.38 special	popular police revolver (R only)	1.155	0.357	110	995	242	185
.357 magnum	popular police and hunting revolver (R and A)	1.290	0.357	125	1450	583	330
.44 magnum	hunting revolver (R only)	1.290	0.430	180	1610	1036	551
.45 auto	popular military handgun (R and A)	0.898	0.451	185	1000	411	324
Colt .45	cowboy "sixgun" (R only)	1.285	0.452	225	920	423	352

Key: R=made for revolver; A=made for semi-automatic; velocity in fps

View common rifle and handgun cartridges

Examples of other less common cartridges include: 30 luger, an automatic cartridge rarely seen in this country; 32 S&W, 32 S&W long, 32 Colt, 32 Colt long, all small caliber (0.312) outdated revolver cartridges; 32 H&R magnum, a relatively new high velocity revolver cartridge; 32 auto, a popular European pocket automatic cartridge; 38 S&W, 38 short Colt, 38 long Colt, outdated revolver cartridges; 44 S&W special, the parent cartridge of the 44 magnum, occasionally used as a police revolver cartridge.

What can be learned from specific cartridge data? If the 44 magnum is compared with the 357 magnum, the effect of bore diameter is seen. The larger area of the 44 magnum creates more force with the same pressure, allowing the 44 magnum to produce more energy at the muzzle. The effect of case capacity can be demonstrated in a comparison of the 9 mm parabellum (para) with the 357 magnum. These cartridges have similar diameters and pressures, but the 357 magnum is much longer, yielding more case volume (more powder), and delivers more energy. Finally, despite the Colt 45 having the largest bore diameter and one of the longest cases, it does not deliver the maximum energy because the outdated 1873 design of this cartridge case severely handicaps its pressure handling capability.

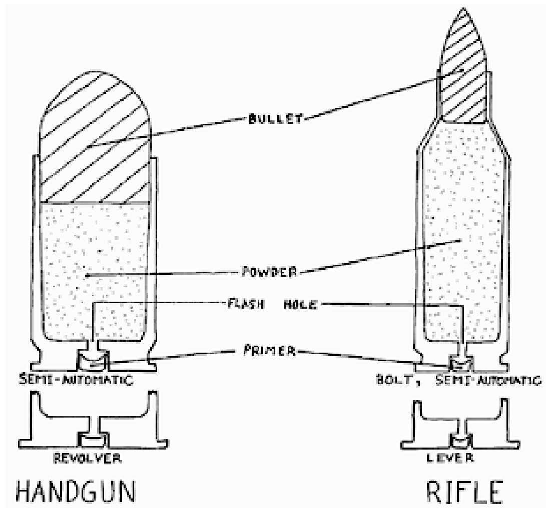
The Glasser "safety slug" has been designed to consist of a hollow copper jacket filled with #12 birdshot. It has been designed in several calibers. When the bullet hits the target, the pellets are released over a wide area. However, the pellets quickly decelerate over a short distance, so they may penetrate poorly and are less likely to hit surrounding targets. They are designed to stop, but not kill, an attacker while avoiding injury to bystanders. At close range, they may produce substantial injury.

The Winchester "Black Talon" cartridge, which comes in several calibers, is designed with a lead core locked to a copper alloy jacket by a unique notching process that is done to prevent separation of teh core and the jacket on target impact via controlled expansion. This expansion is desinged to occur in a delayed fashion at the muzzle velocities of the bullet in order to provide deeper penetration. In addition, the jacket is thicker at the tip than at the heel, with precutting of the thick portion to that, upon target impact, six sharp copper points are raised in a radial fashion. The purpose of this design is to increase expansion and cavitation with greater transference of energy. In one study with test firings, black talons penetrating plastic sheeting (simulating elasticity of skin) expanded irregularly, while those fired into ordnance gelatin (simulating soft tissue) uniformly expanded. The copper points create a potential hazard in bullet removal by surgeons or forensic scientists. (Russel et al, 1995)

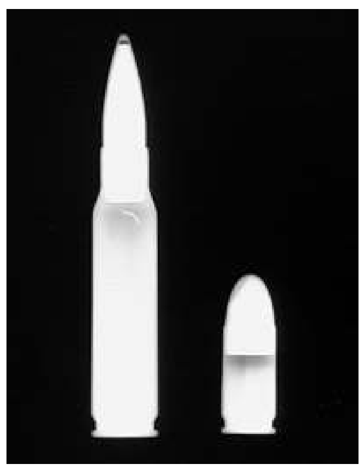
"Shotshell" cartridges containing pellets are available in a variety of calibers. In a study by Speak et al (1985), it was found that, in handguns, either shorter barrel length or larger caliber produced larger pellet patterns.

Armour-piercing bullets are designed to penetrate soft body armor (such as bulletproof vests worn by law enforcement officers). Though they penetrate such armor, they produce no more wounding than ordinary bullets of similar size. Some have teflon coatings to minimize barrel wear with firing. They may demonstrate less deformation when recovered.

Diagrammatic representations of standard handgun and rifle cartridges are shown below. The metal casing encloses the powder, above which the bullet is seated. The powder is ignited through the flash hole when the primer is struck. A case with a rim is found with revolver and lever action rifle cartridges, and also with some some bolt action and semi-automatic rifles.



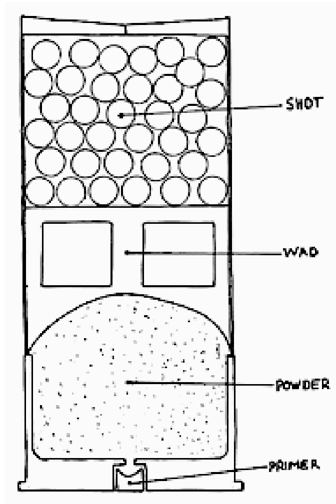
The radiographic appearance of a .308 rifle cartridge and a 9 mm Luger handgun round are shown below to demonstrate the seating of the bullet in the casing.



Shotgun Ballistics

Wounding is a function of the type of shot, or pellets, used in the shotgun shell. Weight, in general, is a constant for a shell so that 1 oz of shot would equal either 9 pellets of double O buckshot or 410 pellets of #8 birdshot. A 00 or "double ought" pellet is essentially equivalent to a low velocity .38 handgun projectile. The spread of the pellets as they leave the muzzle is determined by the "choke" or constriction of the barrel at the muzzle (from 0.003 to 0.04 inches). More choke means less spread. Full choke gives a 15 inch spread at 20 yards, while no choke gives a 30 inch spread at the same distance. (DeMuth et al, 1976) A "sawed-off" shotgun has a very short barrel so that, not only can it be concealed more easily, but also it can spray the pellets out over a wide area, because there is no choke.

A shotgun shell is diagrammed below:



At close range, the pellets essentially act as one mass, and a typical shell would give the mass of pellets a muzzle velocity of 1300 fps and KE of 2100 ft/lb. At close range (less than 4 feet) an entrance wound would be about 1 inch diameter, and the wound cavity would contain wadding. At intermediate range (4 to 12 feet) the entrance wound is up to 2 inches diameter, but the borders may show individual pellet markings. Wadding may be found near the surface of the wound. Beyond 12 feet, choke, barrel length, and pellet size determine the wounding.

If the energy is divided between the pellets, it can be seen that fewer, larger pellets will carry more KE, but the spread may carry them away from the target. Pellets, being spherical, are poor projectiles, and most small pellets will not penetrate skin after 80 yards. Thus, close range wounds are severe, but at even relatively short distances, wounding may be minimal. Range is the most important factor, and can be estimated in over half of cases, as can the shot size used. (Wilson, 1978) A rifled slug fired from a shotgun may have a range of 800 yards. (Mattoo et al, 1974)

Shotgun slugs can produce significant injury, because of the slug's size and mass. At close range, survival is rare. In treating shotgun injuries, it is necessary to remember that the plastic shell carrier and the wadding (which may not appear on radiographs) can also cause tissue damage and may need to be found and removed. (Gestring ML et al, 1996)

The Polyshok Impact Reactive Projectile (IRP) is a form of shotgun ammunition with a lead bead core encased within a single, plastic projectile. The lead core is designed to disintegrate on impact so that lead fragments are distributed over a small area. This reduces the likelihood of exit or collateral damage on missed shots. This projectile produces a single entrance wound, and both plastic and lead components can be found within the wound, regardless of the range of fire. The single entrance wound with limited area of tissue damage suggests a shotgun slug, while the small lead fragments within the wound suggest small size shot pellets, but together these findings are characteristic for the IRP (Nelson and Winston, 2007).

Rifle Ballistics

Many different cartridges are available using different loads and bullet designs. Some of these are outlined in the table below to compare and contrast the ballistics.

Representative Centerfire Rifle Cartridges								

Cartridge	Bullet Type	Bullet Weight (grains)	Velocity (muzzle) in fps	Velocity (100 yds) in fps	Velocity (500 yds) in fps	Energy (muzzle) in ft-lbs	Energy (100 yds) in ft-lbs	Energy (500 yds)in ft-lbs
.22 hornet	H	46	2690	2042	841	740	426	72
.223 Rem*	J	55	3240	2759	1301	1282	929	207
.243 Win	P	100	2960	2697	1786	1945	1615	708
.30-30 Win	R	150	2390	1973	973	1902	1296	315
.308 Win*	J	150	2750	2743	1664	2468	1996	904
.30-06 Spr	P	180	2600	2398	1685	2701	2298	1135

Representative Rimfire Rifle Cartridges						
Cartridge	**Bullet Type**	**Bullet Weight (grains)**	**Velocity (muzzle) in fps**	**Velocity (100 yds) in fps**	**Energy (muzzle) in ft-lbs**	**Energy (100 yds) in ft-lbs**
.22 target	S	29	830	695	44	31
.22 LR	S	40	1150	975	117	84

Key: R=round nose; P=pointed; J=jacketed; H=hollow point; S=semi-pointed; Rem=Remington; Win=Winchester; Spr=Springfield; LR=long rifle; *=military usage

Air gun ballistics

These weapons, also known as "BB" (ball-bearing) guns, fire .177 or .22 round pellets at muzzle velocities of 200 to 900 fps. Though considered of low energy and relatively "safe" for children to use, they can cause severe injury, such as to the eye, and even to abdominal organs. The projectile can penetrate to a depth of 25 mm at a range of 1 meter and up to 15 mm at a range of 5 meters. (Grocock, et al) Air guns are usually never included in gun regulation. Homicide and suicide have been reported with air guns. (Cohle et al, 1987; DiMaio, 1975)

Proceed to Patterns of Tissue Injury.

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