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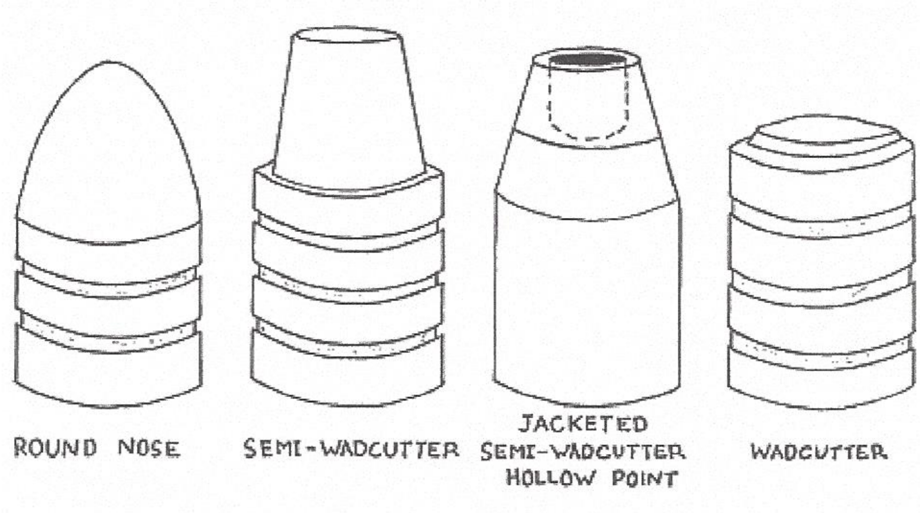
Terminology

- Action: The part of a firearm that loads, fires, and ejects a cartridge. Includes lever action, pump action, bolt action, and semi-automatic. The first three are found in weapons that fire a single shot. Firearms that can shoot multiple rounds ("repeaters") include all these types of actions, but only the semi-automatic does not require manual operation between rounds. A truly "automatic" action is found on a machine gun.
- Barrel: The metal tube through which the bullet is fired.
- Black Powder: The old form of gunpowder invented over a thousand years ago and consisting of nitrate, charcoal, and sulfur.
- Bore: The inside of the barrel. "Smoothbore" weapons (typically shotguns) have no rifling. Most handguns and rifles have "rifling".
- Breech: The end of the barrel attached to the action.
- Bullets: The projectile. They are shaped or composed differently for a variety of purposes.
    - "round-nose" - The end of the bullet is blunted.
    - "hollow-point" - There is a central cavity in the bullet nose not covered by a metal jacket that creates expansion when a target is struck, creating more damage.
        - "Action 4" - Hollow-point projectile made of nonfragmenting brass with radiopaque plastic tip.
        - "Hydra-Shok" - Hollow-point projectile with soft deformable anterior and hard posterior core.
    - "jacketed" - The soft lead is surrounded by another metal, usually copper, that allows the bullet to penetrate a target more easily.
    - "wadcutter" - The front of the bullet is flattened.
    - "semi-wadcutter" - Intermediate between round-nose and wadcutter.
    - "semi-wadcutter" - Features of both semi-wadcutter and hollowpoint.



- Butt or buttstock: The portion of the gun which is held or shouldered.
- Caliber: The diameter of the bore measured from land to land, usually expressed in hundredths of an inch (.22 cal) or in millimeters (9mm).
- Cartridge: Also called a "round". Made up of a case, primer, powder, and bullet.
- Centerfire: The cartridge contains the primer in the center of the base, where it can be struck by the firing pin of the action.
- Chamber: The portion of the "action" that holds the cartridge ready for firing.
- Choke: A constriction of a shotgun bore at the muzzle that determines the pattern of the fired shot.
- Double-action: Pulling the trigger both cocks the hammer and fires the gun.
- Double barrel: Two barrels side by side or one on top of the other, usually on a shotgun.
- Gauge: Refers to the diameter of the barrel on a shotgun in terms of the number of lead balls the size of the bore it would take to weigh one pound (10 gauge, 12 gauge, etc.) ".410 gauge" really refers to caliber, but is worded as such to refer to a shotgun.
- Hammer: A metal rod or plate that typically drives a firing pin to strike the cartridge primer to detonate the powder.
- Ignition: The way in which powder is ignited. Old muzzle-loading weapons used flintlock or percussion caps. Modern guns use "primers" that are "rimfire" or "centerfire"
- Lands and grooves: Lands are the metal inside the barrel left after the spiral grooves are cut to produce the rifling.
- Magazine: This is a device for storing cartridges in a repeating firearm for loading into the chamber.
- Magnum: For rifles and handguns, an improved version of a standard cartridge which uses

the same caliber and bullet, but has more powder, giving the fired bullet more energy. For shotgun loads, magnum shells have more powder and may have increased length with more shot pellets.

- Muzzle: The end of the barrel out of which the bullet comes.
- Pistol: Synonym for a handgun that does not have a revolving cylinder.
- Powder: Modern gun cartridges use "smokeless" powder that is relatively stable, of uniform quality, and leaves little residue when ignited. For centuries, "black powder" was used and was quite volatile (ignited at low temperature or shock), was composed of irregularly sized grains, and left a heavy residue after ignition, requiring frequent cleaning of bore.
- Primer: A volatile substance that ignites when struck to detonate the powder in a cartridge. "Rimfire" cartridges have primer inside the base, while "centerfire" cartridges have primer in a hole in the middle of the base of the cartridge case.
- Revolver: Handgun that has a cylinder with holes to contain the cartridges. The cylinder revolves to bring the cartridge into position to be fired. This is "single-action" when the hammer must be cocked before the trigger can fire the weapon. It is "double-action" when pulling the trigger both cocks and fires the gun.
- Rifling: The spiral grooves cut inside a gun barrel that give the bullet a spinning motion. The metal between the grooves is called a "land".
- Rimfire: The cartridge has the primer distributed around the periphery of the base.
- Safety: A mechanism on an action to prevent firing of the gun.
- Shotgun: A gun with a smoothbore that shoots cartridges that contain "shot" or small metal pellets (of lead or steel) as the projectiles.
- Sights: The device(s) on top of a barrel that allow the gun to be aimed.
- Silencer: A device that fits over the muzzle of the barrel to muffle the sound of a gunshot. Most work by baffling the escape of gases.
- Single-action: The hammer must be manually cocked before the trigger can be pulled to fire the gun.
- Smokeless powder: Refers to modern gunpowder, which is really not "powder" but flakes of nitrocellulose and other substances. Not really "smokeless" but much less so than black powder.
- Stock: A wood, metal, or plastic frame that holds the barrel and action and allows the gun to be held firmly.

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History of Firearms

For millenia man has been fascinated with the idea of launching a projectile at animals--or men of opposing points of view--and has developed more efficient ways of doing so.

- The invention of gunpowder led to the development of firearms. Gunpowder first appeared in use in China over a thousand years ago, but was used primarily in firecrackers and only sparingly in weapons for military use.
- Dissemination of the knowledge of gunpowder manufacture to Europe in the 14th century did not at first lead to military usage.
- However, once the effectiveness of projectiles impelled by the force of gunpowder against both the armor of knight-soldiers and fortifications was known, the use of firearms proliferated rapidly.

Gunpowder, made of a mixture of sulfur, charcoal, and saltpeter (potassium nitrite), owes its explosive force to the fact that 1 mole of solid powder will, when ignited, produce 6 moles of gas. This rapid expansion in the enclosed space of a metal tube could be used to drive a projectile at high speed in a specified direction. Modern gunpowder is simply a refined version of the primitive substance in which the chemical composition has been altered to provide the greatest expansion with the smallest quantity and the least residue. The manufacture of modern powders is standardized enough that gunpowder residue can be analyzed by methods which identify specific components, which can aid the forensic scientist greatly. We will enlarge upon this subject later on.

The greatest stimulus for firearms development was and continues to be military usage. The important needs, militarily speaking, for a firearm included the following: reliability of firing, accuracy of projectile, force of projectile, speed of firing. The reliability issue sparked the development of a number of mechanisms to ignite the powder.

Firing mechanisms developed included:

- Matchlock: Primitive matchlock weapons employed a burning wick on a spring that was "locked" back and released into a pan of powder upon pulling a trigger. The powder in the pan then ignited, sending flame through a small hole into the barrel chamber of the weapon, igniting a larger powder charge in the chamber and sending the projectile (bullet) forward.

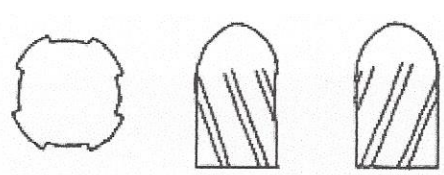
- Wheellock: In the early 16th century, mprovements included the wheellock mechanism in which a spinning wheel against a metal plate showered sparks into the "pan" holding "priming" powder.
- Flintlock: The flintlock developed in the yearly 17th centuryhas a flint was released by the trigger mechanism that strikes a steel plate to shower sparks into the pan filled with powder.
- Percussion: The "percussion" ignition mechanism evolved next in the 19th century and consisted of a "hammer" that was locked and, when released, struck a cap containing a volatile "primer" that ignited on impact, sending a flame through a small tube into the barrel chamber.

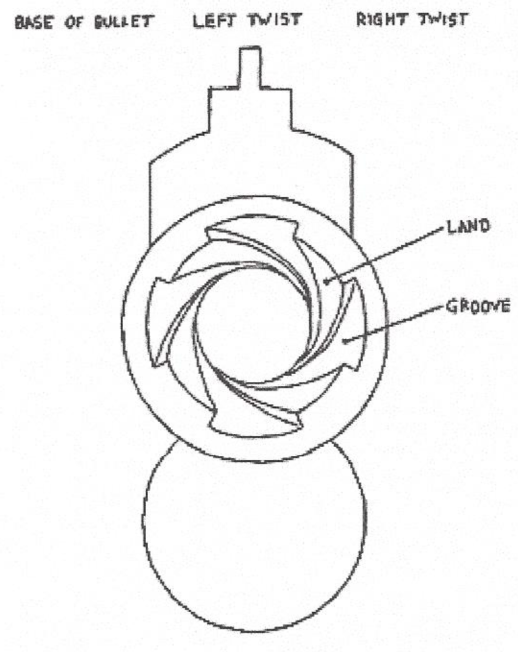
Next, inventors combined the individual components including the bullet, powder charge, and primer all in a single cartridge which could be introduced directly into the chamber. Up to that point, "muzzle loaders" had the powder and bullet loaded from the top of the barrel. These weapons had a "smooth bore" with a round lead ball, both of which limitd range and accuracy.

The accuracy issue was partially solved by using weapons with a longer "bore" or length of metal tube, but there was always a limit to the size of weapon you could carry around. In the 18th century, gunsmiths discovered that putting spiral grooves in the bore would impart a spin to the bullet that improved accuracy markedly. However, grooves had originally been cut to reduce the problem of "fouling" from unburned powder residue. Thus, all modern weapons have "rifling" in their barrels.

Accuracy improved with the use of rifling - metal lands and grooves with a twist inside the barrel of the gun. The bullet gripped the rifling that imparted a spin to the bullet as it traversed the barrel. The spinning bullet that left the barrel had more stability with less tumbling in flight. This produced a more consistent and longer flight path. Thus, accuracy and range improved.

This rifling is slightly different for each weapon, imparting different patterns of deformation on the bullet. These patterns can be used by the forensic scientist to aid identification of a particular weapon used in a crime.





The "breechloading" firearms developed in the late 19th century led to another advantage--speed of loading. Further improvements consisted of multiple chambers, as in the revolver, for multiple shots. Other mechanisms included various "actions" associated with sliding or pumping motions that loaded successive cartridges into the chamber--the so-called "repeating rifle." Toward the end of the 19th century, inventors like Henry Maxim and Richard Gatling devised schemes for rapidly firing large numbers of "rounds" or cartridges without stopping, thus developing the "machine gun."

Machine guns firing multiple bullets were developed in the late 19th century and were refined in World Wars I and II. Modern assault weapons used by armies around the world utilize a mechanism in which the expanding gasses of the gunpowder provide the force for cycling the mechanism to shoot multiple rounds--up to 600 rounds per minute.

The force of a projectile is related to the kinetic energy (KE) imparted to it, given by the formula:

$$\text{Kinetic Energy} = 1/2\ MV^2 \text{ where M=Mass and V=Velocity}$$

Historically, KE has been enhanced in two ways:

- The first way the KE was enhanced was increasing the "caliber" of the weapon. Caliber refers to the diameter of the bore of the barrel, given in decimal fractions of an inch or, in metric systems, in millimeters. Thus, a handgun or rifle could be referred to as .45 cal or .38 cal (called 45 caliber or 38 caliber) or 9mm.
- The second way modern weapons increase KE is through velocity, as impelled by modern gunpowder, which increases the force tremendously because it increases KE as a square of any increment of improvement in velocity.

Velocities of bullets increased with the use of a "jacket" of a metal such as copper or copper alloys that covered a lead core and allowed the bullet to glide down the barrel more easily than exposed lead. Such bullets are designated as "full metal jacket" (FMJ). Such FMJ bullets are less likely to fragment on impact and are more likely to traverse through a target while imparting less energy. Hence, FMJ bullets impart less tissue damage than non-jacketed bullets that expand. (Dougherty and Eidt, 2009) This led to their adoption for military use by countries adhering to the Hague Convention in 1899.

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Anatomy of Firearms

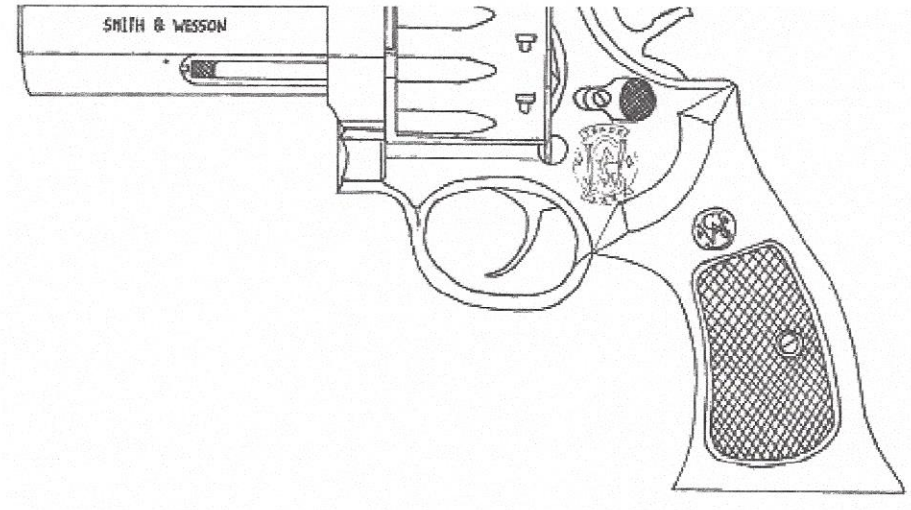
Modern firearms are manufactured in a variety of shapes and sizes to fit multiple purposes. There was a time when the forensic pathologist was faced with a less complex situation, with fewer types, models, and mechanisms available for use. Unfortunately, the proliferation of firearms in this country includes not only sheer numbers but also a staggering array of models. Included in this array are semi-automatic and even automatic weapons built primarily for military usage. However, virtually any type of gun can be found on the streets in use by youth gangs, persons involved in drug trafficking, paramilitary "survivalists" and even what we would consider "ordinary" citizens.

Handguns

From the very start, a handgun was conceived as a compact weapon for self defense. Even though today there are handguns made specifically for target competition or hunting, most are still designed with defense in mind. Thus, handguns are compact for concealability and ease of carrying. This becomes a part of the legal definition of a handgun, as they are considered "concealable" and therefore deemed dangerous and are controlled by law in most states. Of course, a handgun should be capable of firing a projectile accurately at a target. The energy delivered must be sufficient to quell any attack, yet be light enough so that the recoil generated does not wrest the gun from the shooter's hand; this is difficult in practice and there is no perfect choice, so many types of handguns are manufactured for different situations. Finally, since no one can be guaranteed a perfect shot or a single attacker, a handgun must fire multiple shots. The two most common defensive handguns are the double action revolver and the semiautomatic pistol.

Revolver

The revolver has several advantages and unique features. Importantly, they are less expensive to manufacture, simpler in design, and more reliable in operation than semiautomatics. A revolver is easy to master, even for novices. Revolvers with fewer moving parts may be more accurate than semiautomatics. Rrevolvers are limited to six shots, are relatively slow to reload, the gap between barrel and cylinder makes them less efficient, and the trigger pull is greater. The anatomy of a representative double action revolver is shown below:

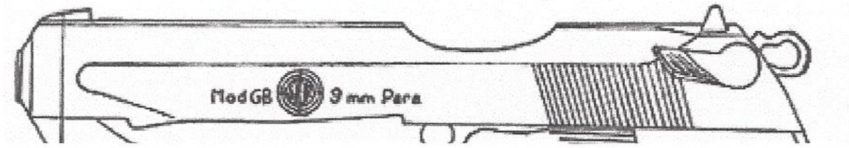


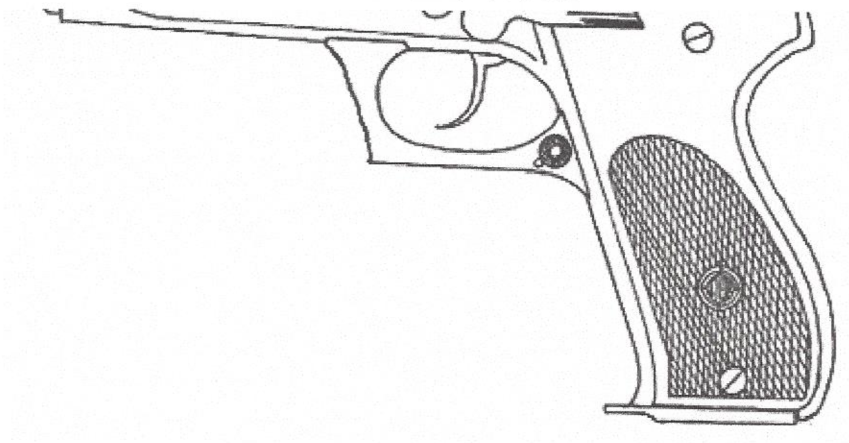
Barrel length is smaller for concealability and longer for accuracy or energy. The ejector rod under the barrel is used to eject fired cartridges before reloading. Sights on a revolver are usually a blade in the front and a notch on the rear. The frame is the largest part, and all other pieces attach to it. Frames are usually made of blued or plated steel, stainless steel, or lightweight alloys. A revolver may weigh less than 1 lb to more than 4 lbs. The cylinder contains five or six holes for the cartridges and can be swung out for easy reloading. This must be a conscious act, so that no empty cartridge cases will be found at a crime scene unless the assailant stopped to reload.

There is a gap between cylinder and barrel to allow the cylinder to turn freely, but this also allows gases to escape laterally, which at close range may deposit gunshot residue on surrounding structures and allow the forensic pathologist to reconstruct the scene. The lockwork translates the trigger pull to rotation of the cylinder, cocking and fall of the hammer. If this is done in one motion of pulling the trigger, it is termed "double-action." Single-action revolvers (old Colts of "cowboys") require manual cocking of the hammer before the trigger is pulled. Different types of grips are employed; larger grips allow more accuracy, smaller grips provide.

Semiautomatic pistol

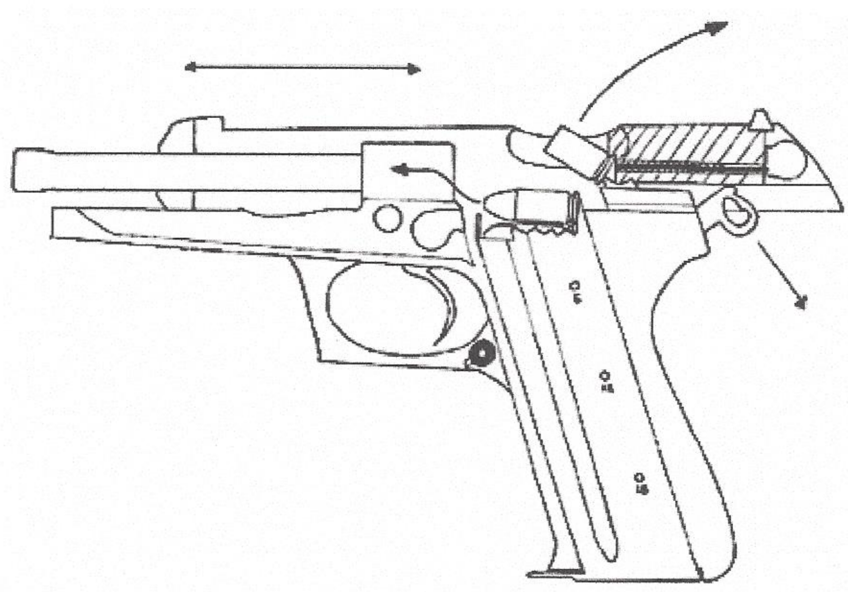
This is a more recent development than the revolver, originating late in the 19th century, mostly through the efforts of John Browning. In fact, almost every semiautomatic handgun available today is a copy of his two most famous designs: the Colt model 1911A government 45 and the Browning Hi Power 9 mm. The anatomy of a semiautomatic pistol is given below:





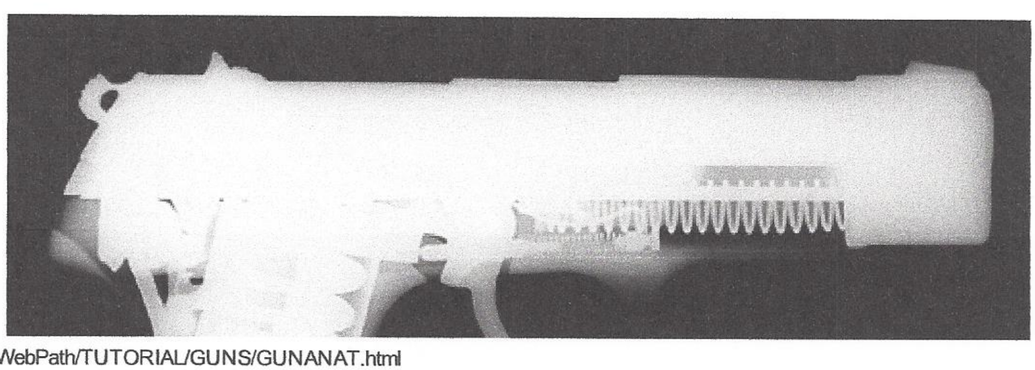
The advantage of semiautomatics is the use of recoil generated by the fired cartridge to eject the empty cartridge case, load the next cartridge, and cock the hammer. This is more conducive to firing multiple shots, so many are designed to carry 15 to 19 rounds. Disadvantages include a more complicated mechanism, require more practice to use, and cartridge cases must be short to work well. Revolver cartridges are more powerful than semiautomatic cartridges for this last reason.

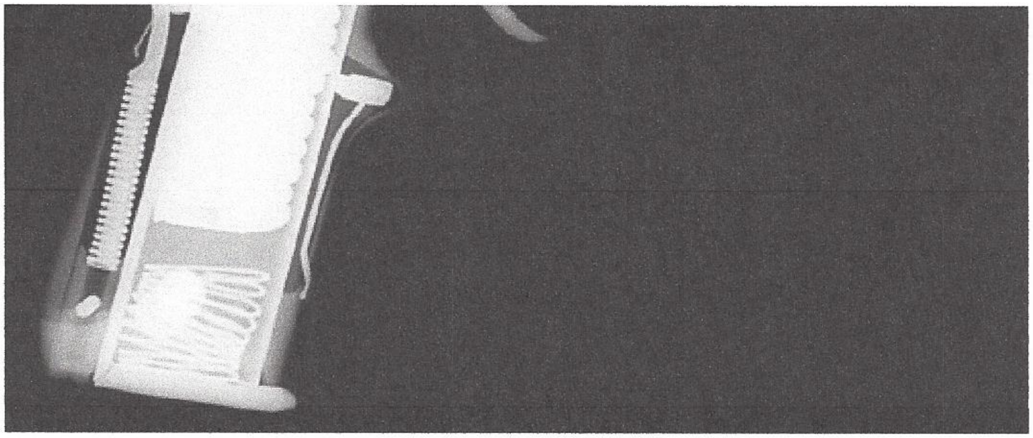
The barrel is normally hidden by the slide. Choices of barrel length are limited. The slide is a key part to the operation of a semiautomatic:



The slide is able to move back along the axis of the barrel under tension from a spring. Since the cartridge base rests on the slide, the slide does just that under the force of recoil generated by the firing of the cartridge. As the slide and empty cartridge case are accelerating backwards, the case is struck by a stationary piece of metal that bumps it to the side. This is conveniently located next to a hole in the slide, so that the empty cartridge case continues its acceleration in a direction perpendicular to the pistol and into the air, landing from 2 to 20 feet from the fired gun. The rearward- moving slide also cocks the hammer. After the case is clear the slide hits a stop and the spring tension starts it forward. The magazine spring is pushing on a column of rounds tight up against the bottom of the slide. As the slide comes back by the column of cartridges, it grabs the top one and pushes it forward and up a short ramp into the chamber where the slide locks it in place. The it forward and up a short ramp into the chamber where the slide locks it in place. The radiograph below demonstrates the location of the spring in relation to the slide and the barrel.

The handle, or butt, is more important here because it contains the magazine holding the cartridges. Safety mechanisms prevent accidental firing. Some lock the hammer, while other designs lock the trigger. In the radiograph below, a loaded magazine is present in the handle.





Even on open ground ejected cases may be difficult to find, as they typically roll into a hiding place such as grass or small depressions in the ground. Thus, ejected cases will virtually always be left behind at the scene, but must be searched for diligently.

Rifles

Rifles differ from handguns in the length of the barrel and the presence of a butt stock. They are harder to carry, are poorly concealable, and more loosely regulated than handguns. However, they are much more accurate and shoot more powerful cartridges than handguns. Rifles may be manufactured as single shot, but most commonly are bolt action, used for large caliber hunting rifles. Military rifles are seimiautomatic or automatic, having a detachable magazine holding 5 to 50 rounds. Pump action and lever action rifles, usually of lower caliber, have magazines below the barrel.

Shotguns

Shotguns have a similar external appearance to rifles, but differ in the lack of rifling inside the barrel, which is the basis for their legal definition. A shotgun shell may contain one large projectile (called a slug), a few pellets of large shot, or many tiny pellets. Shotguns are available in single shot (break action), double barrel, pump action, and semiautomatic.

Other types of firearms

The single action revolver has remained popular for its historic appeal, reliable design, and uncanny balance. For some reason a single action Colt 45 is easier to shoot from the hip

than a modern revolver, and is used almost exclusively in trick shooting.

Semiautomatic versions of submachine guns (such as the Uzi) are classed as pistols for legal reasons. These often have the ability to hold 20 to 30 rounds, but are otherwise identical to conventional handguns in similar caliber. The expense of such weapons precludes their use by most criminals, but they may be used by persons involved in organized crime, drug-dealing, and gangs.

Air guns which use pneumatic pressure to fire a projectile are generally known as "BB guns" and have been around for over 200 years. Three mechanisms are employed:

1. Air is pumped into a pressure chamber reservoir and released by trigger pull
2. A spring compression system is used to drive a piston to compress air (most "toys" are of this variety)
3. A pressurized, carbon dioxide filled cartridge is attached. (Harris et al, 1983)

Even though cheap "Saturday night specials" are readily available, youths and youth gang members may attempt to build their own firearms. Typically, they are crude, and adapted to fire available ammunition. In one study, such guns caused unusual muzzle imprints, intensive soot deposits at the entrance wounds and on the hands, intensive CO-effects, burns, and in one case a skin laceration of the hand holding the weapon. The bullets showed a reduced penetration depth, and characteristic firing marks were missing. (Karger et al, 1995)

Lastly, there has arisen a new group of handguns for hunting big game and long range target competition that are nothing but single shot rifles with shortened barrels and no buttstock. These shoot rifle or hybrid rifle cartridges and deliver rifle energies.

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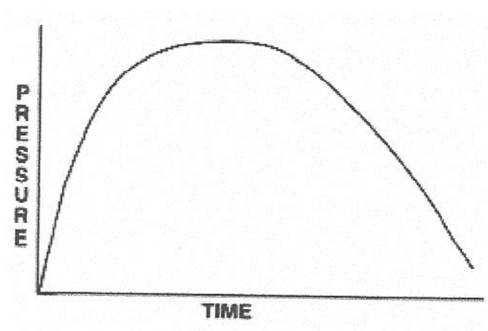
Ballistics

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 (50,000 to 70,000 for rifles psi vs. 30,000 to 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. (Bruner et al, 2011)

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 within the barrel. 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

Kinetic Energy (KE) = 1/2 MV²

Velocity (V) is usually given in feet per 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:

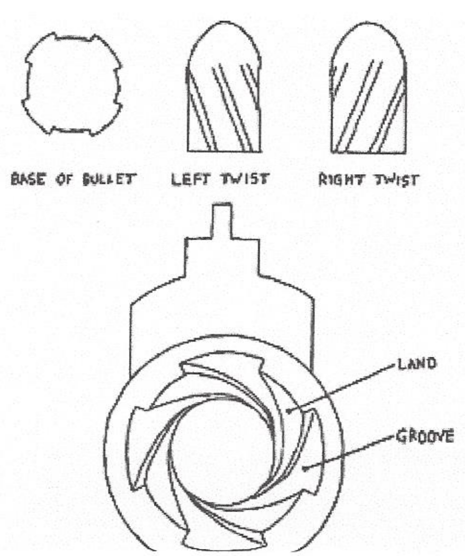
r = D / M

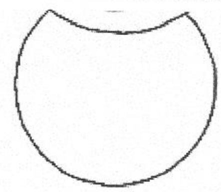
Drag is difficult to measure, so the Ballistic Coefficient (BC) is often used:

BC = SD / I

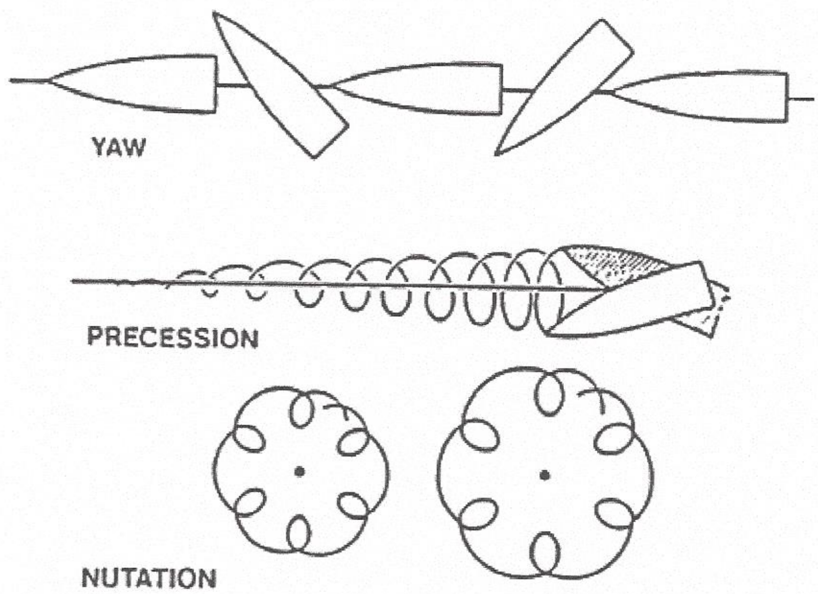
SD is the sectional density of the bullet, and I is a form factor for the bullet shape. Sectional density is calculated from the bullet mass (M) divided by the square of its diameter. The form factor value I decreases with increasing pointedness of the bullet (a sphere would have the highest I value).

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:



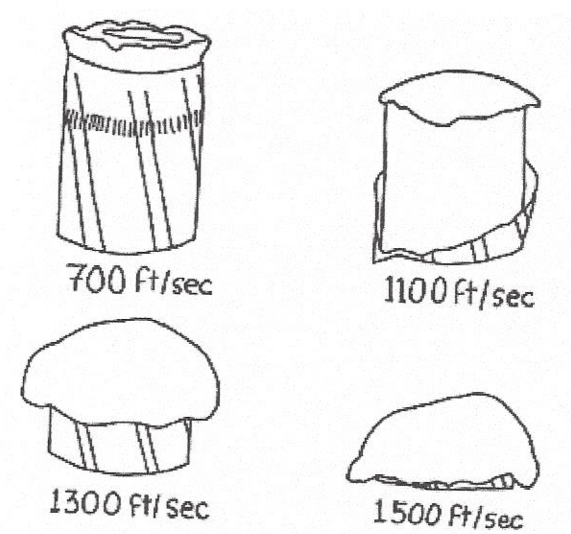
Yaw refers to the rotation of the nose of the bullet away from the line of flight. Precession refers to rotation of the bullet around the center of mass. Nutation refers to small circular movement at the bullet tip. Yaw and precession decrease as the distance of the bullet from the barrel increases.

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 much of its energy. Light spheres would be retarded the greatest within tissues and release more energy, but might not even get to the target. A good aerodynamic compromise bullet 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 hard steel 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 turn, and even 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).

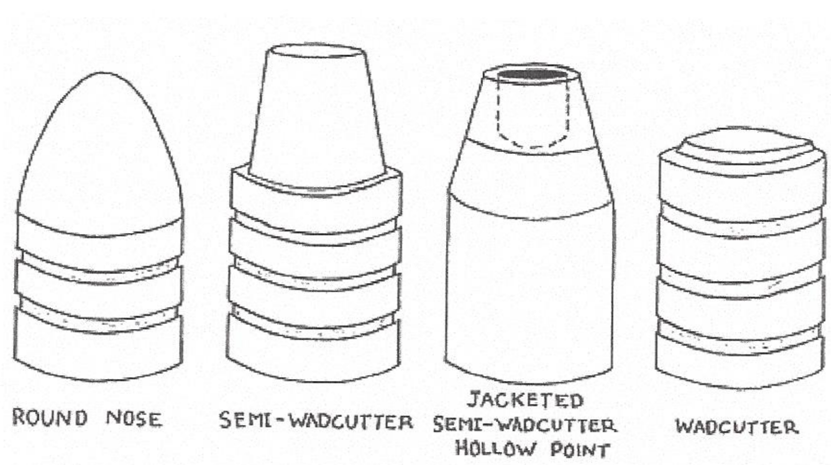
The following images illustrate bullet deformation and damage:

- **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:



"Frangible" bullets are designed to disintegrate upon striking a hard surface. Such bullets are typically made of a metal other than lead, such as copper powder compacted into a bullet shape, as 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. A frangible bullet composed of a powder is designed to disintegrate upon impact, delivering all KE, but without significant penetration; the size of the fragments should decrease as impact velocity increases.

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 SIG	popular police pistol (A only)	0.865	0.381	115	1550	614	N/A

.357 magnum	popular police and hunting revolver (R and A)	1.290	0.357	125	1450	583	330
.40 S&W	rimless police pistol (A only)	0.850	0.421	165	1150	484	342
10 mm	same projectile as .40 S&W (A only)	0.992	0.421	165	1425	744	N/A
.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
.50 AE	Big game and metallic targets (A only)	1.285	0.540	325	1400	1415	930

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.

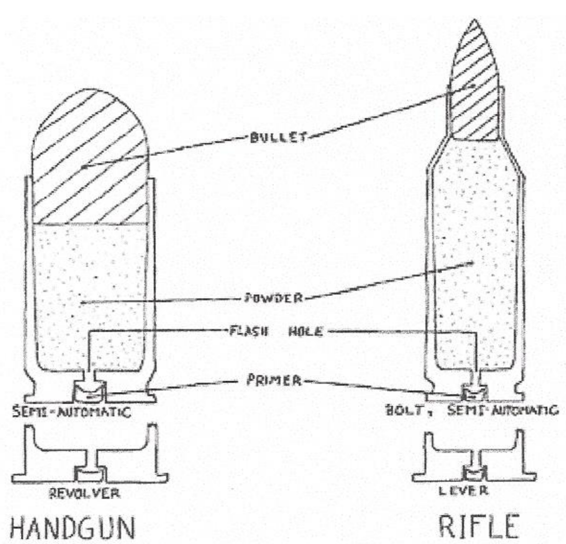
The Glasser "safety slug" has been designed to consist of a hollow copper jacket filled with #12 birdshot. It has been designed in several calibers. When the bullet hits the target, the pellets are released over a wide area. However, the pellets quickly decelerate over a short distance, so they may penetrate 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)

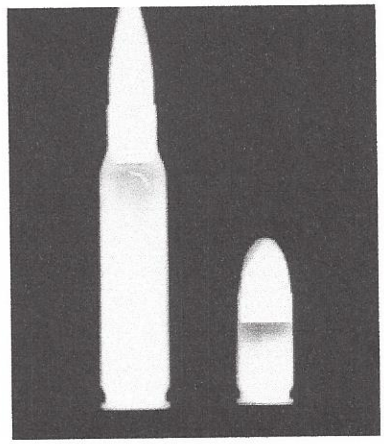
"Shotshell" cartridges containing pellets are available in a variety of calibers. In a study by Speak et al (1985), it was found that, in handguns, either shorter barrel length or larger caliber produced larger pellet patterns.

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.



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

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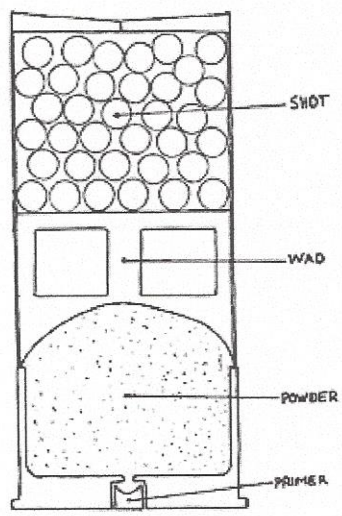
Shotgun Ballistics

Standard shotgun shells contain the powder, wadding, and shot, enclosed in a plastic or cardboard casing, as diagrammed diagrammed below:



There are three standard sizes of shells, based upon their length: 2 3/4", 3", and 3 1/2". The length determines the amount of powder, and the amount of ounces of shot can vary within the shell, based upon the size and number of shot pellets. A "magnum" load has slightly more powder and more pellets, so that the muzzle velocities are not greatly increased, but the total kinetic energy is greater because of the greater mass of pellets. A greater number of pellets increases the likelihood of hitting a target at longer ranges, because of the dispersal pattern of the pellets that increases with range. The amount of kinetic energy possessed by any individual pellet can vary, based upon multiple variables and interactions among the shot mass.

The size of pellets varies from large "000" to small "9". Larger pellets have more kinetic energy, but fewer pellets disperse rapidly and accuracy in hitting the target is an issue. Greater numbers of smaller pellets have a better chance of hitting the target, but each pellet has a small amount of kinetic energy. For example, a skeet shooter trying to hit the clay pigeon wants many smaller pellets capable of hitting the target at a shorter range, while a deer hunter wants larger pellets capable of inflicting greater damage at longer range.

Shot may be primarily composed of lead or steel, along with combinations of other metals. The main reason for use of steel shot is environmental, to reduce lead contamination, but steel has inferior ballistic qualities from an energy standpoint (less mass), but can be partially overcome by increasing powder loads and velocities.

The spread of the pellets as they leave the muzzle is determined by the "choke" or constriction of the barrel at the muzzle (from none 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 (less than 18 inches) 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.

Representative Shotgun Choke		
Designation	**Choke (in thousandths of an inch)**	**% Increase over Cylinder**
None	0"	None
Skeet	0.005"	13%
Modified	0.020"	27%
Full	0.040"	35%

Key: Increased choke, or constriction, correlates with a tighter pattern of pellet dispersion, and % increase over cylinder; cylinder = barrel caliber with no choke

Standard birdshot sizes range from:

Shot Number (Size)	Diameter (in inches)	
9	0.08	
8.5	0.085	
8	0.09	
7.5	0.095	
7	0.10	
6	0.11	
5	0.12	
4	0.13	
3	0.14	
2	0.15	
1	0.16	
B	0.17	

BB	0.18	
BBB	0.19	
T	0.20	

Standard buckshot sizes range from:

Shot Number (Size)	Diameter (in inches)	
4	0.24	
3	0.25	
1	0.30	
0	0.32	
00	0.33	
000	0.36	

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)

Shotgun shells can be loaded with a variety of objects as projectiles, ranging from rubber pellets to needle shaped metal "flechettes" to rock salt to pepper balls. These have a novelty aspect, but their usefulness is questionable. Some, such as the "bean bag" with a fabric bag containing shot, is purportedly "less lethal" have been utilized in law enforcement.

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 ounce 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.

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 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 up to 800 yards. (Mattoo et al, 1974)

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).

The following tables provide data on shotgun shell ballistics (http://www.shotgunsportsmagazine.com/downloads/shotgun_statistics.pdf):

Representative Shotgun Shells							
Shot Type	**Pellet Size (dia. in inches)**	**# of Pellets**	**Weight (ounces)**	**Velocity (muzzle) in fps**	**Velocity (50 yds) in fps**	**Energy (muzzle) in ft-lbs per pellet**	**Energy (50 yds) in ft-lbs per pellet**
7.5	0.095	350	1	1200	610	3.97	1.02
8	0.090	410	1	1200	590	3.37	0.82
9	0.080	585	1	1200	555	2.38	0.51

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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Patterns of Tissue Injury

Classification

One of the commonest determinations of the forensic pathologist is the range of fire. Gunshot wounds are typically classified as:

1. Contact
2. Intermediate range
3. Distant range

Example images demonstrating gross and microscopic appearances of gunshot wounds:

1. **Sooting of hand, gross**
2. **Contact range gunshot wound, gross**
3. **Contact range gunshot wound, gross**
4. **Contact range gunshot wound, gross**
5. **Contact range gunshot wound, gross**
6. **Blood spatter on hand, gross**
7. **Gunshot entrance wound with GSR, microsopic**
8. **Intermediate range gunshot wound, gross**
9. **Intermediate range gunshot wound, gross**
10. **Entrance-exit wound, close proximity from low angle of bullet entrance, gross**
11. **Exit gunshot wound, gross**

Entrance Wounds

Contact wounds characteristically have soot on the outside of the skin, and muzzle imprint, or laceration of the skin from effects of gases. Contact wounds of airguns usually lack these features (Cohle et al, 1987). Intermediate, or close-range, wounds may show a wide zone of powder stippling, but lack a muzzle imprint and laceration. The area of powder stippling will depend upon the distance from the muzzle. (Denton et al, 2006)

Distant range wounds are lacking powder stippling and usually exhibit a hole roughly the caliber of the projectile fired.

The most difficult problem is distinguishing a distant from a contact wound. The factors that can affect the amount and distribution of gunshot residue (GSR) on skin and clothing include: (1) firing distance, (2) length and diameter of the firearm barrel, (3) characteristics of the gunpowder, (4) angle between the firearm barrel and target, (5) characteristics of the cartridge, (6) the environment (moisture, wind, heat), (7) type of clothing, (8) intermediate targets, and (9) characteristics of the target (tissue type, putrefaction, blood marks) (Tugcu et al, 2006).

Scanning electron microscopy of entrance wounds shows gunshot residue within collagen fibrils. The entrance wound appears abraded, with loss of the papillary pattern and laceration of basement membrane (Torre et al, 1986). Computer assisted image analysis may aid detection of GSR (Tugcu et al, 2006).

Entrance wounds into skull bone typically produces bevelling, or coning, of the bone at the surface away from the weapon on the inner table. In thin areas such as the temple, this may not be observed. Sternum, iliac crest, scapula, or rib may show similar features. These observations may permit determination of the direction of fire. A small, dense projectile may "punch out" a rounded portion of cranium, while a larger projectile may produce circumferential fractures that radiate outward from the point of entrance. (Jandial et al, 2008)

The pattern of fractures may permit identification of the sequence and direction of fire. Puppe's rule states that when two or more fracture lines of the skull produced by different blunt forces intersect, it is possible to reconstruct the sequence of injuries. The presence of bone damage from an initial injury causes subsequent injuries to stop in the point of intersection with the previous wounds. In the skull, the fracture lines produced by a second gunshot stops at pre-existing fractures of the skull. (Viel et al, 2009)

Example images demonstrating gunshot wounds to skull:

1. **Skull, contact range gunshot wound, gross**
2. **Bullet track through skull, diagram**

Tangential entrance wounds into bone may produce "keyhole" defects with entrance and exit side-by-side, so that the arrangement of bevelling can be used to determine the direction of fire. (Dixon, 1982) (Denton et al, 2006)

Dixon (1984a) has described how the direction of fire of a graze gunshot wound of the skin surface can be determined by careful examination of the so-called skin tags located along the lateral margins of the graze wound trough, by use of a dissecting microscope or hand lens. Characteristically, the side of the tag demonstrating a laceration is the side of the projection toward the weapon.

"Shoring" of entrance wounds can occur when firm material is pressed against the skin, such as when a victim is shot through a wooden, glass, or metal door while pressing against it to prevent entry of an assailant. A study by Dixon (1980) showed that such wounds have a

greater wound diameter and demonstrate greater marginal abrasion than control wounds produced by the same weapons. The features were directly proportional to the KE of the projectile and the rigidity of the shoring material. Stellate radiating lacerations of some shored wounds could lead to misinterpretation of distant range of fire as a contact wound.

(Denton et al, 2006)

Use of silencers (or "muzzle brakes" to deflect gas and recoil) may produce atypical entrance wounds. A silencer is a device, often homemade, fitting over the muzzle that attempts to reduce noise by baffling the rapid escape of gases. Their possession is illegal. Entrance wounds produced when silencers are present lead to muzzle imprints that are erythematous rather than abraded and disproportionately large for the size of the wound. Entrance wounds may appear atypical at close range. (Menzies et al, 1981)

Firearm missile emboli ("wandering bullets") are rare, with only 87 reported through 1984, but may occur in victims that survive for some time and may require surgical intervention. (Chapman and McClain, 1984)

Can a bullet that is fired skyward cause death? Rare cases of fatal injury have occurred. However, a terminal velocity of 200 feet per second (fps) must be reached to penetrate skin, and a bullet fired vertically would have to fall base first, without tumbling, to exceed 200 fps. A bullet fired at a high-arching angle would have to maintain a flight path without tumbling and land nose forward to maintain sufficient velocity to achieve tissue penetration. Such events are possible, but improbable. (Rapkiewwicz et al, 2013) (Hyneman and Savage, 2006)

Shotgun shells contain variable numbers of round metal pellets, and the characteristics of entrance wounds vary with the range of fire. Contact range approximates the barrel diameter. At increasing distances, there is dispersion of the pellets. Dispersion also depends upon the "choke" or constriction of the barrel intended to keep the pellets grouped more closely. Portions of the shotgun wad or casing may also strike a target and leave an impression, but are unlikely to penetrate skin; they are unlikely to go beyond 20 yards. The pellet size and muzzle velocity determine the energy of individual pellets, and their ability to penetrate the target. The mass of pellets also interacts, with pellets impacting each other to diminish their energy and increase their dispersion from the point of aim. At a distance of 5 yards, the pellets are likely to be individually dispersed. Size of an entrance would can approximate that of the size of the pellet (Drake, 1962). Dispersal of pellets can be defined as a "dispersion index" that is proportional to the square root of the ratio of potential strain energy to kinetic energy possessed by the shot mass as the muzzle. Pellets acquire radial velocity from their interaction to produce the spread pattern (Nag and Sinha, 1992).

The ballistic properties of shotgun shells are complex because of multiple projectiles fired simultaneously that interact and spread out to affect their energy relayed to a human target. Intermediate targets such as clothing can affect penetration into tissues. Using a standard 12-gauge shotgun with modified choke and no. 8 shot ammunition, the protection afforded by fabrics to reduce penetration of shotgun pellets into tissues was greater at increasing distance from the muzzle beyond 40 yd (36.6 m). Thicker denim and cotton fabrics provided slightly greater protection than polyester. (Cail and Klatt, 2013)

Shotgun slug entrance wounds approximate the size of the slug but at close ranges the blast effect may create a wound larger than the slug diameter. A "sabot slug" has an hour-glass shape, and yawing of the slug can create a larger entrance wound than the slug diameter. The soft lead of the slug may cause deformation upon impact (Gestring et al, 1996).

Entrance wounds associated with black powder handguns are associated with extensive sooting, a long range of travel of the sooting into the wound, and skin burns. Large pocket-like underminings may be seen even in deeper tissue layers with contact range wounds. (Karger and Teige, 1998)

The skin defect at the entrance site occurs from multiple mechanisms. Most of the defect results from skin fragmentation with fragements carried into the bullet track. The negative pressure of temporary cavitation pulls skin particles into the wound. There is also backspatter of skin particles away from the direction of bullet travel upon entrance. (Perdekamp et al, 2005)

Infection may result from gunshot wounds. Bullets are not sterile objects, either before or after firing. Bacteria are ubiquitous on skin surfaces and clothing. The bullet carries bacteria into the wound track. Skin particles serve as a transport vehicle for the bacteria. (Perdekamp et al, 2006)

Burn injury at the entrance site with close contact range is typically a minor component of the tissue injury, but some coagulative necrosis does occur. (Tschirhart et al, 1991). Toy cap guns with no projectile, may produce injury via burn alone. (Maze and Holland, 2007).

Bullet Tracks

The track made by the diameter of the bullet (caliber plus change in size through deformation) is a permanent cavity lined by crushed tissue and cellular debris. Adjacent to this track is a region in which the pressure wave created by the bullet causes outward stretching and shearing forces that produce tissue contusion, termed a temporary cavity, which lasts just milliseconds. The higher the velocity of the bullet, the more kinetic energy, and the greater the temporary cavity size, which may be more than 10 times the caliber of the bullet. Rifle bullets generally have a high velocity >2000 feet per second (fps) while bullets fired from handguns have lower velocity. Bullets that traverse tissue without deformation or tumbling impart less kinetic energy and are more likely to exit the body. (Bruner et al, 2011).

Deformation of the bullet, fragmentation of the bullet or secondary targets such as bone, and amount of kinetic energy imparted to tissues, as well as tissue characteristics affect patterns of tissue injury. The higher the specific gravity of tissue, the greater the damage. Elasticity reduces 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 little tensile strength and 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. Fragmentation increases the permanent cavity size (Maiden, 2009; Bruner et al, 2011).

Formation of the temorary cavity exerts pressure waves and shearing forces. These forces can rupture blood vessels to allow blood to escape. The extracellular tissue matrix with collagen, reticular, and elastic fibers can be disrupted. Thus, a contusion of tissue surrounding the bullet track can fill the track with blood and interstitial fluid, as well as cause edema of contused tissue.

Within the cranial cavity, formation of a temporary cavity is restricted, and pressure waves can damage tissues via contusion away from the permanent bullet track. These intracranial pressure effects most immediately affect the brain stem, while edema and neocortical effects may develop over days to weeks. (Jandial et al, 2008)

For lower velocity cartridges, particularly those designed for handguns, bullets that deform and expand, such as hollow-point projectiles, produce the greatest increase in volume of disrupted tissue, along with fragmentation, and are less likely to produce an exit wound. Full metal jacket projectiles typically designed for use with rifles are more likely to exit. Both full and partial metal jacket projectiles may ricochet off bone. At low muzzle velocity the difference between a permanent and temporary cavity is small; at high velocity the temporary cavity is larger. (vonSee et al, 2009)

For frangible bullets designed to fragment upon impact, the wounding capacity depends upon the nature of the surface impacted, the material comprising the bullet, and the velocity. If the compacted material, often copper powder, is very fine (ultra-frangible), then disintegration may occur upon impact or soon after penetration of soft tissues, creating many small tracks similar to an explosive projectile. If the bullet is composed of less fragile particles that are more compact, then disintegration may not occur until impact with harder tissues such as bones, teeth, or fibrous fascia. Fragments less than a gram may penetrate soft tissues to a depth of 10 to 15 cm. If an intermediate target is present, such as clothing, then fragmentation may occur even before tissue entry. If fragmentation does not occur readily, then the bullet may produce cavitation similar to a jacketed projectile of the same caliber. Even though frangible rounds are designed to minimize ricochet and collateral injury to other persons nearby, variability in fragmentation, and impact upon intermediate targets such as glass, may produce a shower of secondary fragments with enough energy to cause injury. (Komenda et al, 2013)

For shotgun slugs, a large amount of energy is transmitted to the tissues. The slug has a large mass and large diameter, deforming ("pancaking") upon impact, or breaking into fragments, so that most of the kinetic energy is absorbed by tissues. The "sabot slug" has an hour-glass shape with hollow base and is designed for use with a rifled barrel for more accuracy at greater distance because of its smaller mass than the standard rifled slug. Its shape causes it to tumble upon impact to produce a larger wound (Gestring et al, 1996).

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.

examiner to determine what can be known from examination of the evidence.

Exit Wounds

Most bullets are designed to hit the target without exiting, for this imparts all the bullet's KE to the target and does the most damage. However, in many situations an exit wound will be present. This may be due to the use of a projectile more powerful than necessary, or the projectile may strike an area (such as an extremity) with minimal tissue.

Exit wounds are generally larger than entrance wounds because the bullet has expanded or tumbled on its axis. Exit wounds either do not exhibit gunshot residues or far less residues than associated entrance wounds. In bone, typical "bevelling" may be present that is oriented away from the entrance wound. (Denton et al, 2006)

Scanning electron microscopy of exit wounds shows irregular lacerations with protruding collagen fibers, but relatively undamaged papillae. (Torre, 1986)

Fragmentation of the bullet may produce secondary missiles, one or more of which may have exit wounds. The bullet path may be altered by striking bone or other firm tissues, such that the bullet track may not be linear, and exit wounds may not appear directly opposite entrance wounds.

It is important to remember that the orientation of the bullet track may be positional. The victim may have been shot while standing or sitting, but when the body is typically examined at autopsy, it is lying down, so that soft tissues may shift position. This must be remembered when rendering opinions as to the angle, or direction, of fire.

If the exit wound is "shored" or abutted by a firm support such as clothing, furniture, or building materials, then the exit wound may take on appearances of an entrance wound, such as a circular defect with an abraded margin. This can occur with contact, close range, or distant shots. 92% of shored exit wounds in one study had a round or ovoid defect, and all had some degree of abrasion. The degree of shoring abrasion increased directly with the KE of the projectile and the rigidity of the shoring material. (Dixon, 1981)

A keyhole lesion, typically identified with entrance wounds, has been described with an exit wound. (Dixon, 1984b)

Sequence of Fire

In some situations, pathologic findings may help to establish in what sequence the bullets were fired that caused the injuries. For example, multiple gunshot wounds to the head may produce fracture lines, and a subsequent fracture line typically does not cross a pre-existing fracture line (Viel et al, 2009).

Subjective reasoning would suggest that the first shot may be horizontal (victim upright) but subsequent shots would be oriented down or to the back of the victim as he fell or fled. Without witnesses and scene investigation, such opinions would be conjectural.

Sexton and Hennigar (1979) have reported cases in which examination of projectile collisions have aided in determining the sequence of fire.

The management of gunshot wounds may require accounting for all bullets and bullet fragments to determine the need for surgery. A simple rule of accounting for bullets is as follows: the number of entrance wounds must equal the number of exit wounds plus bullets retained. An unequal number may result from bullet fragmentation or from embolization, migration, or ricochet to unsuspected tissue sites.

Radiologic Imaging

Radiographic imaging may be needed to account for retained bullets and fragments and to help determine the bullet track. This has been accomplished for decades with plain film radiography, utilizing multiple projections. Bullets and fragments, including primer and jacket, are radiopague, improving ease of detection. (Folio, McHugh, and Hoffman, 2007).

Computed tomographic (CT) imaging has been applied to forensic investigations. CT provides multiple views with higher resolution than plain film radiography. In addition, radiography post-mortem is not limited by potential hazards of cumulative radiation exposure as would be the case in a living person. Thus, higher amounts of radiation energy, and unlimited dosages, can be utilized. With CT, cross sections can be computationally arranged into three dimensional images. (Jeffery et al, 2008)

MDCT imaging can be superior to conventional radiology for detection of soft tissue injuries. A three dimensional display improves localization of bullets and bullet fragments as well as determining details of fractures present. (Harcke HT et al, 2008).

Use of magnetic resonance imaging (MRI) has been shown to be safe in patients with projectiles composed of lead and/or copper. However, movement and heating of projectiles containing steel may be unsafe for patients, as well as produce artefact interfering with interpretation of the imaging. (Dedini et al, 2013)

Manner (Mode) of Death

The manner of death from firearms injuries can be classified as homicide, suicide, accident, or undetermined. There is no single characteristic appearance of a gunshot wound that defines the manner of death. Such a determination requires analysis of multiple pieces of evidence, including the scene investigation, the examination of the body, ballistics evidence, analysis for gunshot residue, and interviews of persons involved with the decedent and the scene of death.

In many cases, the distinction between death from homicide and suicide must be determined. The presence of multiple entrance wounds may not exclude suicide. Hejna and Safr (2010) determined that only 9% of suicide victims removed clothing from the area of a self-inflicted gunshot wound, and therefore defects present on the clothing are not an absolute criterion for disproving the possibility of suicide. However, if a suicide victim removes the clothing from the area of the future wound, then this is almost always an indication of suicide.

Kohlmeier et al (2001) have analyzed a large series of 1704 suicidal firearms deaths and determined characteristics of those injuries. The type of weapon used was a revolver in 49.8%, an automatic pistol in 19.5%, a rifle in 30.0%, and some other firearm in 0.7%. The site of the entrance wound involved the head in 83.7% of cases, the chest in 14.0%, the abdomen in 1.9%, and a combination of sites in 0.4%. The table below identifies the site of the entrance wound by type of weapon used in suicidal firearms deaths:

Suicidal Firearms Deaths			
Site	Handgun (%)	Rifle (%)	Shotgun (%)
Right temple	50.0	22.9	9.3
Left temple	5.8	3.3	3.7
Mouth	14.5	24.3	31.7
Forehead	5.9	15.7	8.1
Under chin	2.4	9.1	10.6
Back of head	3.6	3.8	1.2
Chest	13.2	15.7	19.9
Abdomen	1.4	1.9	5.6
Other	3.2	3.3	9.9

In the above series, contact wounds were found in 97.9%, intermediate in 2.0%, and a combination of these or an unknown range in the remainder.

In a study of rifle wounds, Molina and DiMaio (2008) found that 96% were contact in nature with suicides, while only 5% were contact with homicides.

Shotgun wound suicides are contact range in 96% of cases, while shotgun wound homicides are contact range in 8% and distant range in 59% (Molina, Wood and DiMaio, 2007)

Injury Patterns and Wound Care

Morbidity and mortality is high with ballistic injuries. Three-fourths of persons with a penetrating gunshot wound to the head die within 48 hours. Criteria for evaluation of injury and management have been devised. (Bruner et al, 2011)

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) 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)

In a study of over 12,000 abdominal gunshot wound patients, selective non-operative management was selected in a fifth of cases, and failed in a fifth of those, predicited by a need for blood transfusion and higher injury score on initial assessment. Those patient who failed the non-operative management had a higher mortality rate. The availability and usage of abdominal radiologic CT imaging along with expertise in the application of criteria for treatment aids in patient management (Zafar et al, 2012).

The use of armor or shielding may modify injury patterns from bullets. Body armor may reduce or eliminate penetration of tissues by a projectile, but not eliminate tissue damage. The term 'behind armor blunt trauma' defines the tissue damage from a pressure wave generated by a high velocity projectile striking body armor. One study showed that such trauma may affect neuronal function in the spinal cord. (Zhang et al, 2011)

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Criminalistics Laboratory Methods

Surgical pathology description of bullets

Each bullet keeps a diary in its own way of where it has been and what it has done. Now that you understand the function of a bullet, many of these changes become easy to interpret. The bullet base will contain irregular dimples marking the pressure delivered there in its acceleration. the bullet sides will bear the markings of the barrel interior rifling. These spiral lines, or striae, contain the micrscopic imperfections of the gun from which it was fired and can be as specific as a fingerprint. The bullet nose carries information about the target, and recognizing these may give a clue to the injury rendered.

Remember in measuring bullets to determine the type of cartridge used that the actual bullet diameter, even of non-deformed bullets, is not the same as the name of the cartridge. Most names have a historic basis and have little to do with any real physical measurements: a .30-06 was named for a .30 caliber cartridge developed in 1906; the handgun cartridges called .357 magnum, .38 special, and 9 mm parabellum have essentially the same .357 inch actual diameter. Therefore, use caution in opinions regarding the type of weapon or cartridge used based upon examination of bullets.

The best surgical pathology description would give dimensions as measured (use vernier calipers for best results), shape, and appearance of surface. Photography will be valuable.

Expansion of a semi-wadcutter hollowpoint bullet increases the frontal area and blunts the shape. The degree to which this happens depends upon the texture of the tissue impacted, the velocity at impact, and the softness of the bullet (usually quite constant). With the exceptions of lung and bone, tissue densities are relatively constant. Velocity is the most important factor.

No change in shape occurs until impact velocity achieves about 800 fps. Between 800 and 1000 fps a slight flattening of the bullet nose can be expected. Over 1000 fps real expansion starts to occur and by 1200 fps the nose is turned over to form a mushroom shape. An interesting artefact of impacts around 1000 fps is the tendency of the copper jacket to be shed from the lead. The jacket stops in the subcutaneous tissue and the bullet will continue to penetrate. This accounts for fragments of copper (with rifling marks) commonly seen as surgical specimens. At velocities approaching 1500 fps the bullet is transformed into a rounded ball of lead and copper. The above results are uniformly valid only in artificial media (such as ordnance gelatin) but correlate with human tissue. Examples follow on the next page:

The soft exposed lead nose on non-full metal jacketed bullets can be imprinted with anything that is penetrated by the bullet. Wood, glass, fabric, plastic, or tissue may leave marks as well as fragments on the bullet tip. Bone struck by bullets may not only fragment the bone, but also split the bullet. Lead round nose bullets can penetrate deeply and strike bone at relatively high velocity and can be cleanly cut in half or shaved vertically. Full metal jacketed round nose bullets are less affected, but are often irregularly flattened upon striking bone. Bullets that come to rest in soft tissue without striking bone are often intact.

Intermediate targets, such as glass, wood, clothing, or even paper, may influence the path, shape, and fragmentation of projectiles. Such factors must be taken into account in the recovery of evidence. (Stahl et al, 1979) Even tempered glass, which shatters and fragments easily on impact, may deflect handgun bullets (low velocity) significantly. High velocity, jacketed bullets will be deflected much less. (Thornton, 1986)

Flattening of shotgun pellets may not necessarily indicate a close range contact with a target, as the pellets may be deformed on firing. Recently developed shells use plastic packing materials and plastic capping to diminish deformation. (DeMuth et al, 1978)

Even pellets of air guns may show characteristic striae (Cohle et al, 1987). Silencers used over the muzzle of a gun are often misaligned and can produce characteristic striae. (Menzies et al, 1981)

Examination of whole bullets and cartridge cases

If a bullet is recovered from the scene or from the body, it may be compared to bullets obtained by test-firing the suspected weapon. Test firing is done using similar ammunition. Bullets are marked on the nose at the 12 o'clock barrel position (called "index", "witness", or "reference" marks). Consecutive test bullets are then fired into a water tank, recovered, and juxtaposed with a comparison microscope to compare test bullets with the recovered evidence. Index marks help to align test bullets to determine reproducibility of markings. Photographs should be taken (a ruler or coin can be used to give scale and alignment).

Comparison of bullets involves "class" and "individual" characteristics. These characteristics are based upon "striae" left on the bullet as it passes through the barrel.

Class refers to the type of caliber and rifling. Rifling pattern may turn to the right or left, with a given rate of twist. The number and depth of grooves can vary also. Some newer guns use "polygonal" rifling resembling the reversed image of a twisted square rod. A particular type of gun (.38 Smith and Wesson, or 9 mm Glock) will impart these class characteristics.

Individual characteristics are used to try and determine if a specific gun (say one of many 9 mm Glocks) was used. These individual characteristics are based upon burrs or imperfections in the barrel, particularly the muzzle, that impart specific markings, or striae, to fired bullets. If such markings are present, they may lead to a "determinative" identification. In general, smaller caliber weapons (.22) yield fewer reproducible characteristics in fired

In general, smaller caliber weapons (.22) yield fewer reproducible characteristics in fired bullets than weapons of larger caliber (.45).

In the image below, two sets of bullets of the same class are roughly compared to indicate how difficult this can be when bullet deformation is present.

Patterns of Striae on Bullets

A system has also been described for identification of jacketed sporting rifle bullets using twelve parameters:

1. Identification number
2. Manufacturer
3. Weight
4. Diameter
5. Cartridge
6. Base design
7. Length of bearing surface
8. Color
9. Shape
10. Location and description of crimping cannelure
11. Location and description of other cannelures
12. Miscellaneous notes.

Such parameters may aid in narrowing the search for suspected weapons or ammunition. (Booker, 1980)

Optical devices for identification of bullets and tool marks include microscopes with cameras. Standard light microscopy has limits of resolution defined by magnification and illumination. Digital cameras are limited by number, color, and density of pixels detected.

Confocal microscopy provides a means for obtaining information regarding depth in an image. (Banno, Masuda, Ikeuchi, 2004)

There are three results of comparison identification. Test fired and recovered bullets can: (1) be related to the same weapon; (2) be unrelated to the same weapon; (3) not be compared with this type of examination. Conclusions should not be based upon probabilities in test firing. Image analysis can be employed to assist the process of bullet comparison and identification of the weapon used to fire the bullet. (Brinck, 2008)

Criteria for consecutively matching striae (CMS) have been established. Bullet striations are typically three dimensional because there is depth and contour imparted in a deformable metal such as lead. Matching of these three dimensional toolmarks is based upon the presence of at least two different groups of at least three consecutive matching striae that appear in the same relative position, or one group of six consecutive matching striae, oompared to a test toolmark. (Chu et al, 2012)

In many situations, however, the hospital pathologist as medical examiner will not be involved with test firing. The hospital pathology department may receive bullets or bullet fragments from patients. Such evidence should be clearly identified, with a "chain of custody" followed. The pathologist will dictate a report and release the evidence back to the authorities.

Every firearm that is fired imparts a set of physical markings to the fired bullet and cartridge case. Components of the firearm that produce these unique characteristics are: firing chamber, breech face, firing pin, ejector, extractor and the rifling of the barrel. These unique characteristics assist forensic scientists in determining what firearm was used to fire the bullet. Characteristics transferred to the cartridge case include: firing pin impression, center of firing pin impression, and ring of firing pin impression. In one study these features could correlate the cartridge case to the firearm 96.7% of the time. (Md Ghani et al, 2010)

Examination of bullet fragments or bullet composition

In many cases, recovered bullets will be too deformed for comparison studies. The "lead" of bullets actually may contain up to 26 common elements, of which up to 12 can be used for differentiation. One of the most common of these is antimony (1 to 2%) Unfortunately, bullets within a box or lot do not have uniform composition, but there may be distinct groups of bullets within a box. (Haney and Gallagher, 1975) (Koons and Grant, 2002)

When analysis of the bullet lead is necessary, but a copper jacket is present, the copper may be most efficiently removed, without contamination of the lead, by use of concentrated nitric acid. (Izak-Biran et al, 1980)

Detection of the type of bullet (jacketed or not) may be done by a dithiooxamide (rubeanic acid) test. This test detects copper and nickel, which may be components of jacketed ammunition, on the target. The rubeanic acid forms a dark green precipitate in the presence of copper, pink or blue with nickel, and brown with cobalt. Blood and other materials on the target produced false negatives. (Lekstrom and Koons, 1986) target produced false negatives. [illegible]

Bullet particles may also be detected in bone fragments from skeletal remains when no soft tissues remain. After determining that radiopaque particles are present, surfaces of the bone fragments containing the particles can be exposed by cutting. The surfaces can then be analyzed by SEM-EDA and by electron probe microanalysis to identify lead (Pb) and antimony (Sb). The electron probe technique aids in differentiating antimony from abundant calcium of bone. (Simmelink et al, 1981) Detection of bullet lead has also been carried out with proton-induced X-ray emission (PIXE) analysis, even in a victim buried for several years (Fischbeck et al, 1986).

Even if an exit wound is present, a search for bullet fragments or jacket material should be done, with radiographs if necessary. A new type of ammunition, Winchester Western Silvertip, may pose a problem, as its aluminum jacket is only faintly radiopaque (Conradi, 1982).

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Examination of Gunshot Residue

Appearances of Gunpowder

All gunpowders are designed to burn quickly to produce rapid expansion of gas in a confined space. In an explosion something gets very big very fast. The burning rate of gunpowder can be classified in three categories:

- Degressive (regressive) burning: gunpowder grains formed in flakes, balls, and sticks have a burning surface area that decreases continuously as the grains are consumed.
- Neutral burning: gunpowder grains that are single perforated and the burning surface area remains relatively constant.
- Progressive burning: gunpowder grains that are multiperforated and rosettes that have a burning surface area that increases continuously as the grains are consumed.

Unburned gunpowders can have recognizable shapes, colors, and sizes of grains. (Pun and Gallusser, 2007)

Composition of Gunshot Residue

Firing a weapon produces combustion of both the primer and powder of the cartridge. The residue of the combustion products, called gunshot residue, can consist of both burned and unburned primer or powder components, and can be used to detect a fired cartridge. Gunshot residue may be found on the skin or clothing of the person who fired the gun, on an entrance wound of a victim, or on other target materials at the scene. The discharge of a firearm, particularly a revolver, can deposit residues even to persons at close proximity, so interpretations as to who fired the weapon should be made with caution. (Dalby et al, 2010)

The major primer elements are lead (Pb), barium (Ba), or antimony (Sb). Usually, all three are present. Less common elements include aluminum (Al), sulfur (S), tin (Sn), calcium (Ca), potassium (K), chlorine (Cl), copper (Cu), strontium (Sr), zinc (Zn), titanium (Ti), or silicon (Si). A mercury-fulminant based primer may be found in ammunition manufactured in Eastern Europe and used in the Middle East.(Zeichner, et al, 1992) Primer elements may be easier to detect in residues because they do not get as hot as the powder. So-called "lead free" ammunition may contain one or more elements including strontium (Sr), zinc (Zn), titanium (Ti), copper (Cu), antimony (Sb), aluminum (Al), or potassium (K). Both titanium and zinc are commonly used in paints and can be contaminants, but the appearance of particles containing them can be distinguished from gunshot residue by SEM. (Martiny et al, 2008) (Dalby et al, 2010)

The cartridge case, bullet, bullet coating, and metal jacket also contain specific elements that can be detected. Virtually all cartridge cases are made of brass (70% copper and 30% zinc). A few have a nickel coating. Primer cases are of similar composition (Cu-Zn). Bullet cores are most often lead and antimony, with a very few having a ferrous alloy core. Bullet jackets are usually brass (90% copper with 10% zinc), but some are a ferrous alloy and some are aluminum. Some bullet coatings may also contain nickel. (Ravreby, 1982).

Modern gunpowder, or "smokeless" powder, can contain up to 23 organic compounds (FBI study). Nitrocellulose is virtually always present, along with other compounds containing nitrate or nitrogen. One of these compounds, diphenylamine (used as a stabilizer in the powder), can be detected using reagents containing sulfuric acid. (Maloney et al, 1982) Modern gunpowders are also described as "single-base" when the basic ingredient is nitrocellulose and as "double-base" when there is additionally 1 to 40% nitroglycerine added. Hardy and Chera (1979) describe a method to differentiate them using a mass spectrometer.

In the physical examination of the scene or body for evidence of gunshot residue, it must be remembered that lead residues may mimic gunshot residue. Lead residues may be found up to 30 feet from the muzzle, and are always present on the opposite side of a penetrated target. Such a situation has been reported when an intermediate target (glass) was present. (Messler and Armstrong, 1978)

The amount and pattern of residue deposited may vary by the gun used to fire the bullet. (Lepik and Vassiljev, 2010) Though the amount of residue deposited tends to decrease with increasing range of fire, the actual deposits can be highly variable for ranges up to 20 cm.(Brown, Cauchi, et al, 1999) GSR has been reported to be found at distances from 6 to 18 meters forward of the shooter, and up to 6 meters laterally. However, climatic conditions significantly influence recovery rates for GSR. (Dalby et al, 2010) Use of atomic force microscopy (AFM) for detection of particle size in relation to range of fire has been described. (Mou, Lakadwar, and Rabalais, 2008)

Detection of Gunshot Residue

The major methods for detection of primer residues are analytical and qualitative. Analytical methods include neutron activation analysis (NAA) as well as atomic absorption spectrophotometry (AAS) and inductively coupled plasma mass spectroscopy (ICP-MS). Scanning electron microscopy with energy dispersive analysis by x-ray detector (SEM-EDX) and atomic force microscopy (AFM) are used to identify the primer residue

qualitatively. An X-ray analyzer can be beamed directly onto the particles visualized with SEM, so that the energy dispersive pattern can be generated, giving the elemental composition of the particles. For these methods, samples must be obtained from the skin surfaces of a victim at the scene. Delay in obtaining residues, movement, or washing of the surfaces of a victim at the scene. Delay in obtaining residues, movement, or washing of the body prior to autopsy will diminish or destroy gunshot residues. (Molina et al, 2007) A rapid loss in numbers of GSR particles occurs from 1 to 3 hours post firearm discharge, though maximum recovery times of 1 to 48 hours have been reported. (Dalby et al, 2010)

The method of collection for residue is quite simple and easily carried out in the field. The two widely used methods incude collection onto a carbon-coated adhesive stub or with an alcohol swab. Of the two, the stub has fewer false negatives from greater collection efficiency. The swab method may have usefulness when the surface to be tested is smooth, or if propellant analysis is required. The stub can be directly applied to the surface (skin or other material) to be tested. The stub, with the residue on the surface, can be directly prepared for examination in the SEM device. A major advantage of SEM is that it can reveal the actual surface details of the particles examined, for comparison with known examples of gunshot residue, and pictures can be taken. The large particles of partially burned powder and the spheres of residue can be distinguished from contaminant materials. (Reid et al, 2010)

Scanning Electron Micrograph of GSR

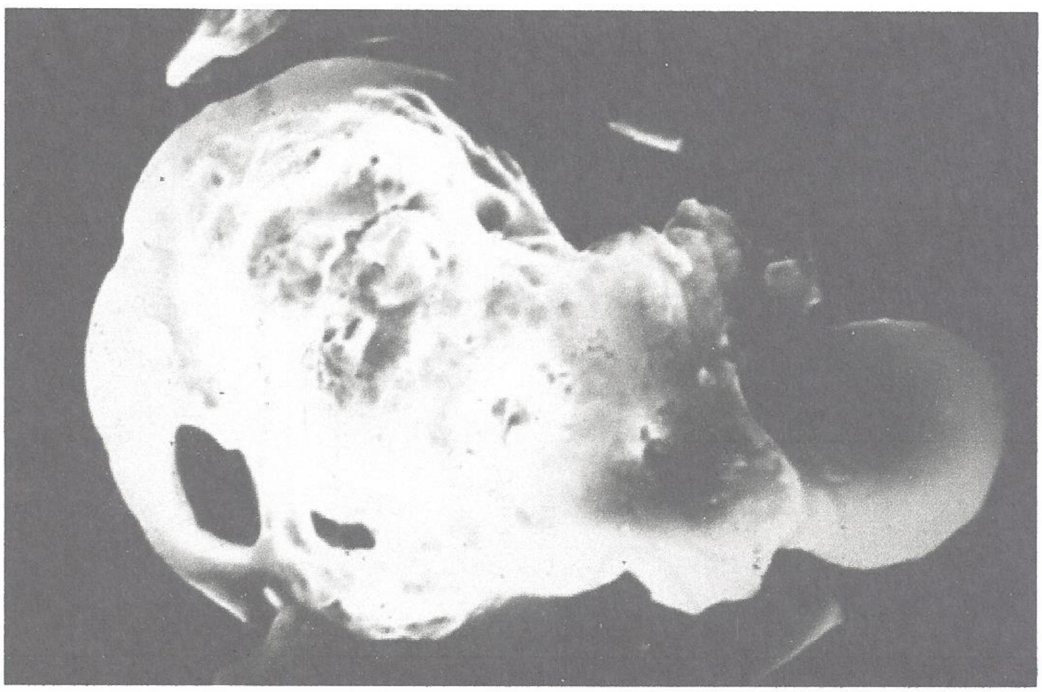
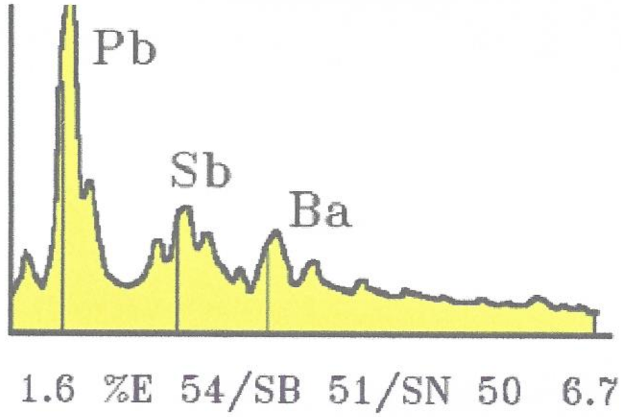


Diagram of the SEM-EDX pattern of GSR



Any hand or body part that was close to the fired weapon may have residue appearing consistent with having fired the weapon. Clothing should always be retained on the body up to autopsy, as this may modify entrance wounds, need examination for gunshot residues, or aid in interpretation of the scene. (Dalby et al, 2010)

The type of weapon can influence the distribution of GSR. For handguns, variables include: barrel length and caliber affecting the plume or cone of gases emitted with their GSR particle; nature of the ejection port of pistols; and barrel-drum gap of revolvers. (Ditrich, 2012)

Gunshot residue analysis requires careful evaluation. False positives may be caused by contamination or transfer of GSR to the body by mishandling, or when the body is heavily contaminated by GSR from previous shooting. However, the number of particles from secondary environmental contamination is low. (Berk et al, 2007) False positives from neutron activation analysis or from atomic absorption spectroscopy assays can be avoided with SEM because of the ability to identify the morphology of particles. False negatives result from washing of the hands (when this area is sampled) or by victim wearing gloves. A rifle or shotgun may not deposit GSR on hands, bur more likely in the crook of the support arm. (Dalby et al, 2010)

SEM may also have usefulness for examination of bullets, as embedded materials from the target such as bone fragments may aid in reconstruction of the scene (DiMaio VJ et al, 1987). SEM has been used to study tool marks made by the firing pin impressions in the primers of spent cartridges. Such findings could be useful to determine which gun was used to fire the cartridge. Grove et al (1972) found that SEM could reveal clearly all surface detail in the impression and that 50% of shotgun impressions and 75% of rifle impressions could be positively identified on the basis of four or more individual characteristics, given similar class characteristics.

Another technique for analysis of GSR is inductively coupled plasma mass spectrometry (ICP-MS). In a study of wound samples microwave-digested and analyzed using ICP-MS to detect all elements present at measurable levels in GSR, shot versus unshot tissues could be distinguished. Additionally, jacketed and nonjacketed bullet types could also be distinguished. (Udey et al, 2011)

The presence of GSR may vary from entrance to exit wounds, for the entrance wound will usually have more than the exit, or the exit will have none. At close range, macroscopic usually have more than the exit, or the exit will have none. At close range, macroscopic examination of the entrance wound is in concordance with microscopic appearance of GSR in all cases, but for distant range gross detection of GSR is negative in a third of cases, though microscopically present. A fifth of exit wounds, though lacking grossly detectable GSR, have microscopic evidence of GSR, thus confounding distinction of entrance and exit wounds by microscopy alone. (Perez and Molina, 2012)

Residue is lacking in entrance wounds with airguns (Denton et al, 2006) (Cohle et al, 1987). The alizarin red S stain can be utilized in microscopic tissue sections to determine the presence of barium as part of GSR (Tschirhart, Noguchi, Klatt, 1991).

It may be difficult to both find and determine the nature of gunshot wounds in a decomposed body. Determination of the range may be particularly difficult. Extreme care should be taken to avoid misinterpretation of the wounds and artefacts.

Other Examinations

Cases have been described in which suicide victims' hands were stained orange-brown from contact with gun barrels following death, presumably from perspiration coupled with a prolonged post-mortem interval of contact. (Norton et al, 1979)

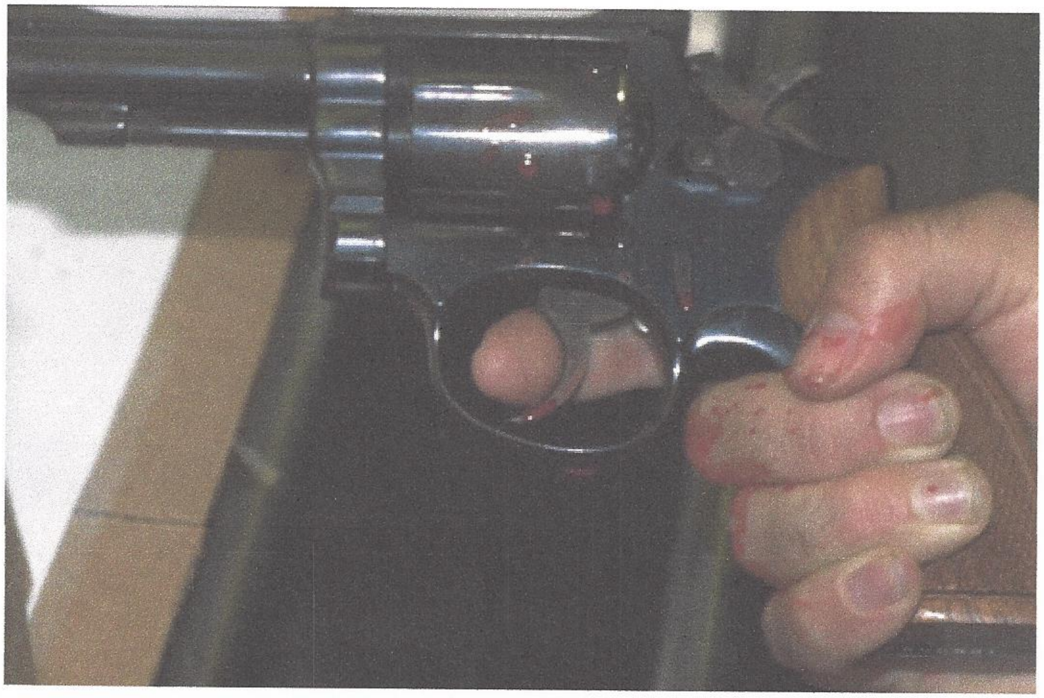
Latent fingerprints may be detectable on cartridges and expended shell casings. Such fingerprints, called latent because they are transferred via a substance on the skin ridges to an object. On a gun, such substances could include cleaning solvents or gun oils. Usually, the substances consist of perspiration mixed with oils from sebaceous glands. Conditions of increased temperature and low humidity decrease the persistence of fingerprints. Brass retains the fingerprints better than nickel-plated materials. (Given, 1976)

Each firearm sold (other than black powder weapons) has a manufacturer's serial number stamped into it which may be used to identify the weapon. Registration of firearms provides a way of tracing gun ownership. However, attempts may be made to obliterate registration numbers by grinding or filing the metal. (Polk and Giessen, 1975)

Gas chromatography has been used to identify gun oils in targets, and was very sensitive, even with stored specimens (Kijewski and Jakel, 1986).

The DNA from cells of assailants can be identified on a firearm or clothing or other objects left at the scene. The cells may be present in blood or body fluids or from epithelium (skin) and left behind on objects recovered upon scene investigation. Sampling for recovery of these biological materials may involve: cutting a portion of material, swabbing a surface, and applying adhesive tape to a surface. Adhesive tape has the advantage of selective sampling to recover epithelial cells while reducing contamination of PCR inhibitors such as dyes in clothing. The technique commonly employed to detect DNA is the polymerase chain reaction (PCR), which detects minute amounts of DNA. (Barash et al, 2010)

So-called "backspatter" describes the deposition of blood from the victim onto the shooter at close range. The pattern of backspatter has been utilized to determine who fired the weapon. Spatter marks may provide clues to the sequence of events, point of origin, and weapon. Spatter marks may provide clues to the sequence of events, point of origin, and direction. (Yen et al, 2003)



In a study using high-speed digital video imaging to visualize blood droplets, firearm muzzle gases, and ballistic shock waves with standard reflected light and shadowgraphy imaging techniques, a significant interaction between air currents, muzzle gases, and particulate material emanating from the firearms upon discharge with backspattered blood was observed. Blood droplets that initially spattered back toward the firearm and the shooter were observed to change direction under the influence of firearm-induced air currents and were blown forward toward and beyond their original source location. Hence, patterns of backspatter are complex and affected by multiple variables. (Taylor et al, 2011)

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Gun Control Issues, Public Health, and Safety

Gunshot wounds impact severely on the criminal justice as well as health care systems. Some basic statistics are important in understanding the magnitude and severity of the social and economic burden to the U.S. The subject remains contentious. (Glantz and Annas, 2009)

In the U.S. for 2010, there were 31,513 deaths from firearms, distributed as follows by mode of death: Suicide 19,308; Homicide 11,015; Accident 600. This makes firearms injuries one of the top ten causes of death in the U.S. The number of firearms-related injuries in the U.S., both fatal and non-fatal, increased through 1993, declined to 1999, and has remained relatively constant since. However, firearms injuries remain a leading cause of death in the U.S., particularly among youth (CDC, 2001) (Sherry et al, 2012).

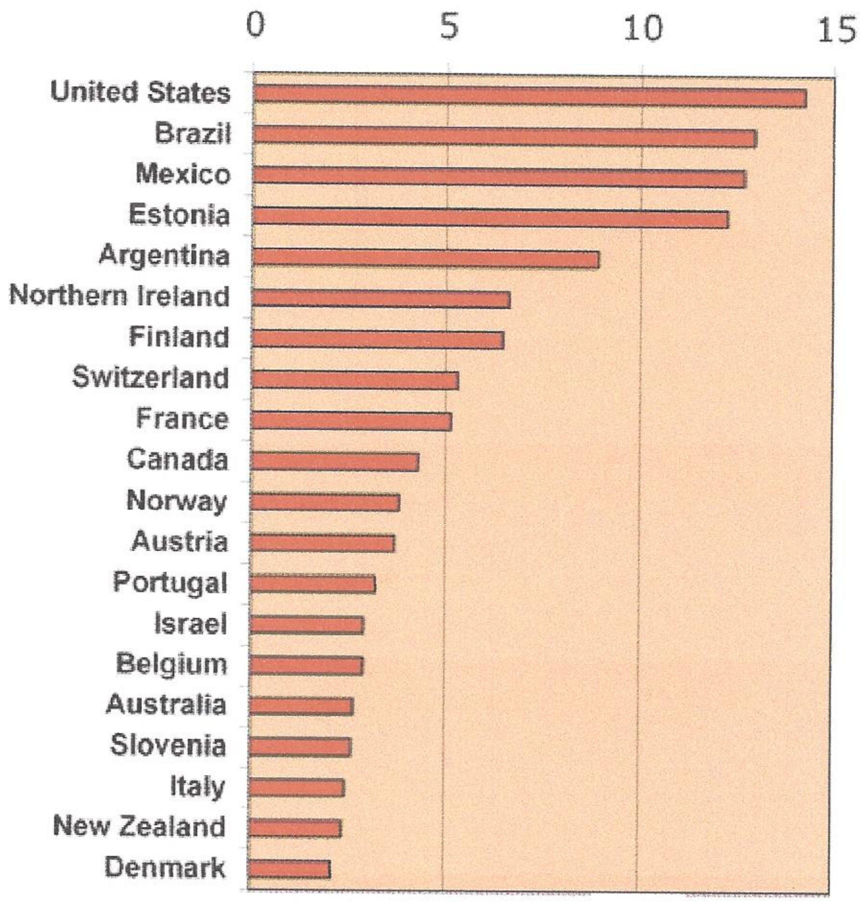
The rates of firearms deaths in the U.S. vary significantly by race and sex. The U.S. national average was 10.2 deaths per 100,000 population in 2009. The highest rate was 28.4/100,000 for African-American males, more than quadruple the rate of 6.3/100,000 for white males. (CDC, 2009)

The number of non-fatal injuries is considerable--over 200,000 per year in the U.S. Many of these injuries require hospitalization and trauma care. A 1994 study revealed the cost per injury requiring admission to a trauma center was over $14,000. The cumulative lifetime cost in 1985 for gunshot wounds was estimated to be $911 million, with $13.4 billion in lost productivity. (Mock et al, 1994) The cost of the improper use of firearms in Canada was estimated at $6.6 billion per year. (Chapdelaine and Maurice, 1996)

A study of firearm deaths in high income countries (Australia, Austria, Canada, Czech Republic, Finland, France, Germany, Hungary, Iceland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovakia, Spain, Sweden, United Kingdom (England and Wales), United Kingdom (Northern Ireland), United Kingdom (Scotland), and the United States) was conducted with data from the World Health Organization assembled by the WHO from the official national statistics of each individual country from 2003 (Richardson and Hemenway, 2011). The total population for the United States for 2003 was 290.8 million while the combined population for the other 22 countries was 563.5 million. There were 29,771 firearm deaths in the US and 7,653 firearm deaths in the 22 other countries. Of all the firearm deaths in these 23 high-income countries in 2003, 80% occurred in the US. In the US the overall firearm death rate was 10.2 per 100,000, the overall firearm homicide rate 4.1 per 100,000, and the overall homicide rate 6.0 per 100,000, with firearm homicide rates highest persons 15 to 24 years of age. For the US the overall suicide rate was 10.8 per 100,000, and slightly over half of these deaths were firearm suicide (5.8 per 100,000). Firearm suicides rates increased with age. In the other high income countries 2003 the overall firearm death rate was 1.4 per 100,000, the overall firearm homicide rate 0.2 per 100,000, and the overall homicide rate 0.9 per 100,000. Firearm homicide rates were highest in the 25 year old to 34 year old age group. The overal suicide rate was 14.9 per 100,000 with a overall firearm suicide rate of 1.0 per 100,000.

A comparison across countries for an earlier time period is shown below.

Firearms Death Rate (per 100,000, age adjusted) for Selected Countries in one year between 1990 and 1995 (Krug, Powell and Dahlberg, 1998)



The number of firearms injuries remains high in the United States, compared with most of the rest of the world. Firearm suicide rates are strongly impacted by the rate of gun ownership. (Kaplan and Geling, 1998) There is a positive correlation between firearm fatality rates and number of guns in developed nations. (Bangalore and Messerli, 2013) The number of firearms in the hands of private citizens in the U.S. far exceeds that of other countries. It might even be said that Americans live in a "gun culture" based upon traditions and behaviors well-entrenched in society. This is reflected in the U.S. constitution, whose second amendment guarantees that "A well regulated militia, being necessary to the security of a free state, the right of the people to keep and bear arms, shall not be infringed." Though the application of this amendment applied to maintenance of a militia, and not private gun ownership, the second amendment has been consistently interpreted to protect private ownership of many types of guns.

Thus, the laws of the U.S. Federal government as well as the states do not as yet severely restrict the manufacture, sale, and use of firearms by ordinary citizens. "Gun control" is a sensitive issue that evokes strong emotions in persons both for and against control. Politicians find it difficult to deal with this issue. There is disagreement as to whether a reduction in access to or numbers of firearms will have a measurable effect upon crime. The Brady Handgun Violence Prevention Act passed in 1994 in the U.S. established a nationwide requirement that licensed firearms dealers observe a waiting period and initiate a background check for handgun sales (but the law does not apply to secondary markets). This law was not associated with overall reductions in homicide rate or suicide rate in the 1990's.(Ludwig and Cook, 2000) Attitudes and tolerances may be reflected in the high visibility of firearms and firearms-inflicted injuries that are portrayed in the media. (Price et al, 1992) One thing remains certain, despite laws for or against gun control, a lack of care and concern regarding one's fellow human beings, whether in war or through domestic violence, will continue to promote firearms injuries.

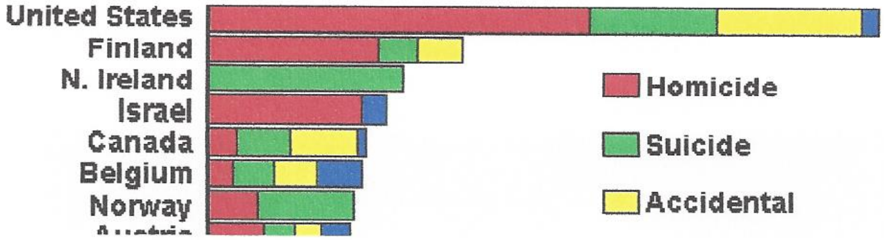
Non-fatal firearms injuries account for a significant number of hospital visits. There were 478,400 fatal and nonfatal firearms incidents in the U.S. of which 97.4% were nonfatal. Of those injured, 75% required medical attention and 80% of those were hospitalized. The rate of nonfatal firearms injuries has declined over the past 2 decades in the U.S. (Kalesan et al, 2013)

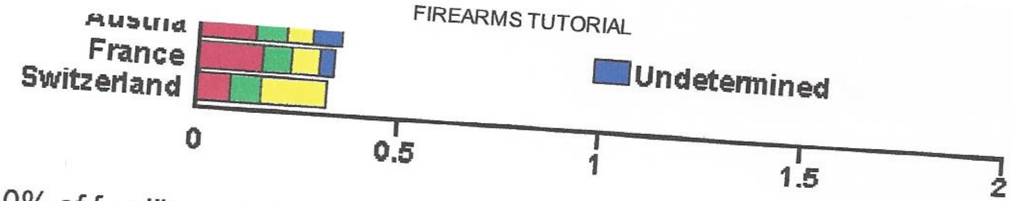
Child safety is an important issue. Accidental shooting deaths are most commonly associated with one or more children playing with a gun they found in the home. (Choi, et al, 1994) The person pulling the trigger is a friend, family member, or the victim. (Harruff, 1992) In the period from 1979 to 2000, accidental firearms deaths involving children declined in the U.S., aided by child access prevention laws and felony prosecution of offenders. (Hepburn et al, 2006) This trend has continued, as reported in a study from 2009 (Safavi et al, 2013). A study of nonnatural deaths in a large American city revealed that half of such deaths in persons from 10 to 19 years of age were due to homicide, and firearms were involved in 88% of them. (Heninger and Hanzlick, 2008)

The table below indicates mode of death for firearms injuries in the ten countries with the most reported deaths from firearms for children less than 15 years of age. (CDC, 1997)

Firearms Deaths by Mode of Death for Children <15 Years of Age

Top 10 Countries - Rate per 100,000





In one survey, 10% of families admitted to having unlocked and loaded firearms within easy reach of children (Patterson and Smith, 1987). Another study showed that two-thirds of accidental firearms injuries occurred in the home, and one-third involved children under 15. 45% were self-inflicted, and 16% occurred when children were playing with guns. (Morrow and Hudson, 1986) A study from 1991-2000 showed that twice as many people died from unintentional firearm injuries in states in the U.S. where firearm owners were more likely to store their firearms loaded. (Miller, et al, 2005)

The issue of "home defense" or protection against intruders or assailants may well be misrepresented. A study of 626 shootings in or around a residence in three U.S. cities revealed that, for every time a gun in the home was used in a self-defense or legally justifiable shooting, there were four unintentional shootings, seven criminal assaults or homicides, and 11 attempted or completed suicides (Kellermann et al, 1998). Over 50% of all households in the U.S. admit to having firearms (Nelson et al, 1987). In another study, regardless of storage practice, type of gun, or number of firearms in the home, having a gun in the home was associated with an increased risk of firearm homicide and suicide in the home (Dahlberg, Ikeda and Kresnow, 2004). Persons who own a gun and who engage in abuse of intimate partners such as a spouse are more likely to use a gun to threaten their intimate partner. (Rothman et al, 2005). Individuals in possession of a gun at the time of an assault are 4.46 times more likely to be shot in the assault than persons not in possession (Branas et al, 2009). It would appear that, rather than being used for defense, most of these weapons inflict injuries on the owners and their families.

Hunting accidents with firearms, despite the large gun ownership in the U.S. and numerous game seasons in most states, remain relatively rare and do not appear to be increasing. (Huiras, et al, 1990) In a study of accidental hunting firearm injuries and fatalities from 1961 to 1992 in Germany, there were 257 cases, most involving experienced hunters. 26% of the gunshot wounds were fatal. 23% of cases were self-inflicted and 77% injuries caused by another person. The firearms/ammunition included shotguns (63%) and shotgun slugs (3.5%), rifle bullets (31%), and handgun butllets (2.5%). 22% of pellet accidents produced severe eyeball injuries. 38% of the wounds occurred at a distance of 5 m or less, including all self-inflicted injuries. The most frequent factors responsible for the accident were: improper handling of the firearm (37%), failure to notice the victim (24.1%), covering the victim while swinging on the game (14.8%), ricocheting projectiles (13.6%), inadequate storage of the firearm (11.7%) and mistaking the victim for game (9.3%). (Karger et al, 1996)

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