BALLISTIC TRAUMA, OVERVIEW AND STATISTICS

S R Naidoo, University of KwaZulu Natal, Durban, South Africa

Introduction

Gunshot wounds are more destructive than most other injuries. An understanding of the biomechanics, together with the effects of the relationship between a high-speed penetrating missile and body tissues, is crucial to both forensic pathology diagnosis and optimal medical management of injuries. The nature of ballistic trauma presents surgeons with immense challenges, especially in regions where gunshot trauma remains prevalent.

The availability of firearms, especially those possessing considerable firepower and magazine capacity, is of great concern. In South Africa, it is estimated that a large proportion of firearms is illegally obtained. Globally, debate on strategies for improved control of gun ownership continues.

This article provides a broad overview of the general characteristics of ballistic trauma and related aspects.

Definitions

Certain terms, and gunshot wound appearances in particular, often confound interpretation because a term may mean different things to different people. The "burn" and even the "blackening" seen in a close-range wound are examples. To ensure unambiguous interpretation, the use of contentious definitions should be avoided.

Ballistics refers to the study of missiles and projectiles (objects in motion) and their effects. Internal ballistics refers to the dynamics of a bullet in motion between the ignition of the propellant and exiting from the firearm muzzle. External ballistics refers to the same during its flight in air. Terminal ballistics refers to the effects produced by a bullet when it strikes or penetrates any target, whereas wound ballistics is terminal ballistics where the body is the target.

History of Ballistic Injury

The origins of gunpowder manufacture are uncertain. Although it is historically recognized that the Chinese invented gunpowder in the thirteenth century, it is believed that the Muslims of Moorish Spain used combustible powder in the twelfth century. The use of gunpowder as a propellant for projectiles began in the early 1300s. Originally, black powder – a mixture of sulfur, charcoal, and saltpeter (potassium nitrate) – was used in cannons and then it was used in a crude type of hand cannon for more than five centuries until the mid-1800s, when smokeless powder was developed. Single-based propellant was developed in France in 1885, and double-based propellant was developed in England in 1889.

The earliest weapons were muzzle-loaders, in which powder and projectile were introduced through the muzzle by a ramrod. Spiral grooves cut on the inside of the gun barrel (rifling) imparted a spin to the emerging bullet and were first used in the early 1500s in sporting rifles only, not in military guns. The introduction of breech loading led to rapid progress in the development of weapons and ammunition. Over time, different types of firearms and ignition systems were developed (Table 1).

Firearms

Modern firearms are either rifled or smooth-bore, and are available in a range of brands and types.

Handgun

The handgun is a small rifled firearm that can be held and fired from one hand. The different types of handguns include single-shot firearms (derringers and air guns), revolvers, and semiautomatic self-loading pistols (Figures 1 and 2).

Rifle

The rifle is similar to the handgun, except that it is larger, has a longer bore, and is usually fired from the shoulder (Figures 3 and 4).

Shotgun

The shotgun is similar to the rifle, except that it is smooth-bore and usually fires a cluster of small

Table 1 Development of firearms and ammunitions

Year	*Development*
1450	Matchlock system
1517	Wheel-lock system
1575	First cartridge
1550	Flintlock firearm
1776	Breech-loading firearm
1807	Percussion systems
1814	Percussion cap
1835	Revolver
1836	Pinfire cartridge
1845	Rimfire cartridge
1858	Centerfire cartridge
1884	Machine gun
1892	Self-loading (semiautomatic) pistol

spherical lead balls (pellets) or a modified single projectile (rifle slug) (Figure 5).

Automatic Firearms

These are capable of automatic fire (continued firing of successive bullets with a single pull and continued pressure on the trigger).

Figure 1 Typical revolver: a 0.38 special (Rossi model no. 27 snub-nose).

Figure 2 Typical pistol (semiautomatic): a 9-mm Parabellum Z88.

- Submachine guns (machine pistols) are held and discharged from the shoulder or hip, and use pistol ammunition fed by a magazine.
- Machine guns are larger, usually crew-operated, and fire rifle ammunition that is usually supplied on belts.

Other

- Homemade guns, country guns, and zip guns are terms used to describe firearms that are often crudely fashioned out of pieces of metal with a simple firing pin. In certain regions of Africa and Asia, where there is large-scale subversive violent activity or guerrilla warfare, “industries” may exist to meet the demand for firearms. They are also made and used by criminal youth and gang members, even in urban areas (Figures 6 and 7).
- Stud guns are industrial power tools used in the building industry that fire metal nails, studs, or fasteners into concrete or steel.
- Penetrating captive bolt instruments are used during the slaughter of animals. A bolt is fired and penetrates the head of the animal, causing a puncture wound several centimeters deep.

The ballistic dynamics are different for stud guns and captive bolt instruments because no free high-speed projectiles are used, and accidental and suicidal deaths have been reported.

The range of different types of ammunition produced today makes ballistic identification a skillful task, requiring extensive knowledge of modern weaponry and ammunition (Figures 8 and 9).

Statistics

Gunshot injuries impact greatly on both the criminal justice and the public healthcare systems, and globally they account for about 120 000 injuries and about 40 000 deaths per year. Statistics are vital in understanding socioeconomic burdens, and although many

Figure 3 Typical (R1) rifle.

Figure 4 AK-47 rifle.

Figure 5 Typical shotgun (12-gauge).

Figure 6 Homemade shotgun made of metal pipe and pieces. Note the simple trigger mechanism.

Figure 7 Homemade shotgun disassembled.

violence- and injury-monitoring systems are in place, a comprehensive universal database is lacking.

Although firearm-related injury and mortality may be declining in certain areas of the world, an increased incidence is noted in other regions, where the number of gunshot injuries from civilian strife has increased to the level seen in military conflicts (Figure 10). The USA has reported a decline in the number of gunshot incidents in recent years. The number of murders by firearm decreased by approximately 27%, from 18 300 in 1993 to 13 300 in 1997, and a similar trend has been seen for nonfatal gunshots. However, it is acknowledged that the rate of all firearm injuries and deaths is still unacceptably

Figure 8 Handgun cartridges (from left to right): 0.22 short, 0.22 long rifle, 7.65 mm, 9 mm short, 9 mm Parabellum, 0.38 Special, 0.357, and 0.45.

Figure 9 Rifle (and a shotgun) cartridges (from left to right): 5.56 × 45 (R4/R5/M16), 7.62 × 39 (AK-47), 7.62 × 51 (R1), and 12-gauge.

high in the USA – second only to traffic injuries as the leading cause of violent death.

In South Africa, there has been a disturbing accelerated incidence of injury and death from firearm use, a phenomenon that is seen in developing countries undergoing rapid sociopolitical and economic transformation. For a South African population in excess of 50 million, an estimated 70 000–80 000 unnatural deaths, mainly from injuries, were recorded in 2001. Most firearm homicides involve young adults (20–34 years of age) and are the leading cause of unnatural deaths in general for all groups between the ages of 15 and 64 years (**Figure 11**).

Changing trends in hospital admissions for penetrating torso trauma in one city (Durban) between 1988 and 1992 showed that stab wounds decreased by 30% while gunshot wounds increased by more than 800% (**Figure 12**). Interesting observations include a higher survival rate of victims with sharp (stabbing) wounds compared to gunshot wounds, reflecting the serious wounding capacity of firearms.

Characteristics of Missile Movement

Characteristics affecting missile movement include velocity, energy, mass, inertia, ballistics coefficient, spin, gravity, shape, air resistance, and other movement during flight.

During flight, a bullet spins on its longitudinal axis, providing stability and allowing for greater distance to be reached. Its velocity adds more to its kinetic energy than its mass. Its inertia will cause it to continue in motion, but it is affected by air resistance, which begins to slow it down progressively, and by gravity, which causes the projectile to assume a curved path (trajectory) in long flight.

The ballistics coefficient of a projectile depicts its capacity to maintain its velocity against air resistance. It is a relationship between mass (m), diameter (d), and a form factor (i) determined by the shape of the bullet, and it is represented by the following formula:

$$c = m/id^2$$

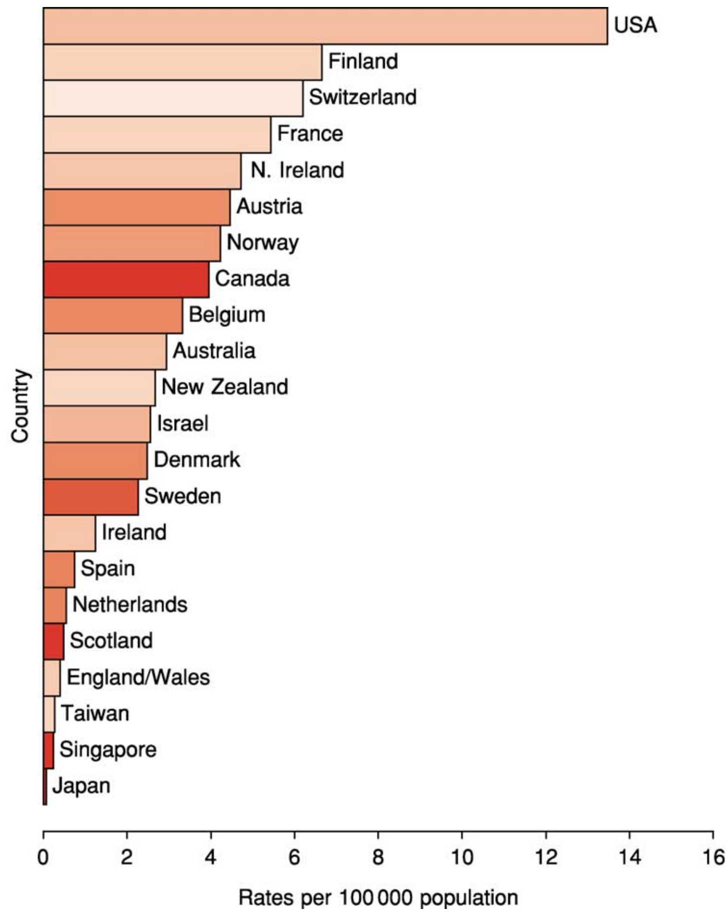

Figure 10 Global firearm death rates, 2001. The data represent combined suicide and homicide gun deaths. Many countries are not represented, largely due to unavailability of data. In South Africa, no crude national mortality rate for firearm deaths is available because mortality surveillance studies only reflect an urban focus.

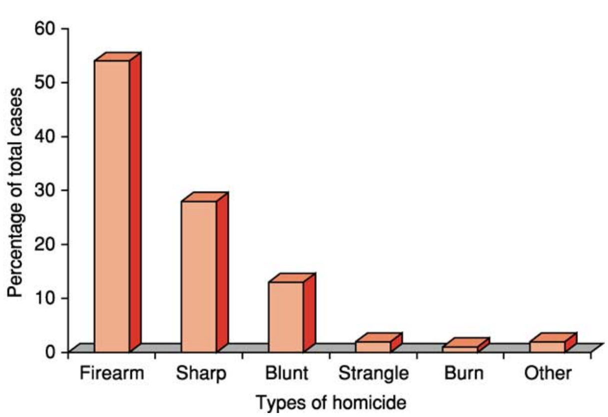

Figure 11 External causes of homicide, South Africa (2001). The data reflect prevailing trends in predominantly urban areas covered by the mortality surveillance system. Deaths by firearms account for more than half of all cases of homicide.

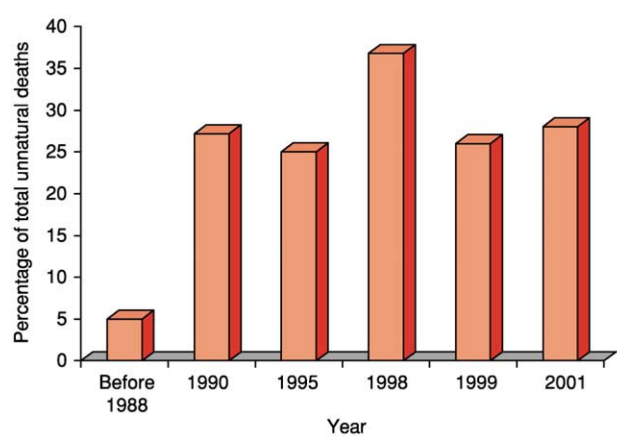

Figure 12 Trends in firearm deaths, Durban, South Africa (1988–2001). The figure shows the unprecedented surge in reported incidence of gunshot fatalities in Durban, a trend observed during the past two decades in metropolitan areas of South Africa. Deaths from gunshots increased from approximately 5% before 1988 to an average of 25–37% and have remained somewhat at a plateau since then.

Projectiles with a larger ballistics coefficient move more effectively and lose less velocity as they travel.

Bullets in motion are unstable because they are affected by many factors. Yaw is a divergence of the long axis of the bullet from a straight line as the tip bobs (wobbles) up and down during flight. This characteristic is important because a large angle of yaw will affect the presenting profile upon impact and contribute to greater kinetic energy loss and damage. Precession is a circular yaw around the bullet's center of gravity that takes the shape of a decreasing spiral as it moves away from the muzzle, and nutation describes a rotational movement in a small circle that forms a rosette pattern like a spinning top, but these have less effect on wounding.

Shotgun pellets are spherical lead balls that have a poor ballistics coefficient and unfavorable aerodynamics. They do not have the penetrating ability of bullets.

High- and Low-Velocity Injuries

Wounds can be classified according to effects due to missile velocity (Table 2).

Wounding Capacity of a Bullet

The capacity to injure depends on the amount of energy dissipated to the tissues as the bullet impacts and passes into the body. This depends on the velocity of the hurtling projectile and on other variables, such as its mass, shape, physical structure, behavior upon impact and entry, and the physical characteristics of the tissues penetrated. The velocity mainly determines the amount of kinetic energy possessed by the bullet, as reflected in the formula for the energy of an object by virtue of its motion:

$$E = 1/2m \times v^2$$

where E is kinetic energy, m is mass, and v is velocity.

Table 2 High- and low-velocity firearms[a]

Type	*Velocity ($m\,s^{-1}$)*
Low-velocity	Less than 366 $m\,s^{-1}$
Medium-velocity	Between 366 and 762 $m\,s^{-1}$
High-velocity	Between 762 and 1260 $m\,s^{-1}$
Very-high-velocity	Greater than 1260 $m\,s^{-1}$

[a]For all practical purposes, despite the above, pathologists usually categorize wounds as either low- or high-velocity on the basis of distinctive and recognizable appearances at autopsy: the breakpoint between these is about 700 $m\,s^{-1}$. Most handguns are low-velocity, whilst rifles are high-velocity firearms, but a few large handguns do edge on to the high-velocity range.

Because bullets possess most velocity at the point of leaving the firearm muzzle, one would expect a greater degree of injury with impacts at closer ranges of fire. Also, a larger, heavier projectile should produce more injury than a smaller one, all other factors being equal. However, these distinctions, when evaluating wounds, tend to be overshadowed by the other significant variables.

Upon puncturing skin and passing into tissues, a rapidly spinning bullet creates a direct path by crushing and tearing the tissue directly ahead. For low-velocity bullets, this is the most significant mechanism of injury.

At the same time, and conspicuously with high-velocity injury, the tissue on either side of the perforating path is violently hurled outward at right angles by forces generated by energy transfer. This produces, directly behind the missile, a large and often spindle-shaped temporary cavity that pulsates vigorously outward back and forth for several milliseconds until it finally settles around the bullet path, forming the permanent visible wound track. Pathologists also refer to a related phenomenon in which shock waves generated ahead of the speeding missile may produce distant injury by propagation of the wave along fluid-filled vessels and organs such as blood vessels, heart, bladder, bowel, and the brain-filled cranial cavity.

It is the extent of the temporary cavity that defines the real amount of the tissue damage, not just the permanent track. The greater the energy dissipated by the bullet, the larger the size of the temporary cavity (and injury), all other factors being equal. The devastating effects of a temporary cavity are seen in high-velocity gunshot wounds, where the cavitation does not regress completely but remains as a larger permanent cavity (Figure 13). Bone fracture from cavitation, however, is very rare. For most practical purposes, cavitation is only of significance in high-velocity injuries (rifles) and it is much less of a factor in low-velocity (most handgun) injuries.

As a general principle, if a bullet exits the body, its energy is only partially lost in the tissues. If a bullet lodges in the body, its total kinetic energy is imparted, and therefore a greater degree of injury is sustained.

The other factors that tend to enlarge the size of the temporary cavity by increasing the energy lost include yaw or tumbling of bullet, bullet deformation and fragmentation, and the density/consistency of the tissues. Although stabilized by its spin after leaving the barrel, a bullet still possesses some instability due to initial yaw or wag and, if striking tissue at this point, will be more destructive; this partially explains the tendency for greater destruction at closer ranges of fire. The yaw is soon reduced in flight, but it begins to increase later when losing velocity. Yaw is also greatly increased after the bullet passes through tissue: its

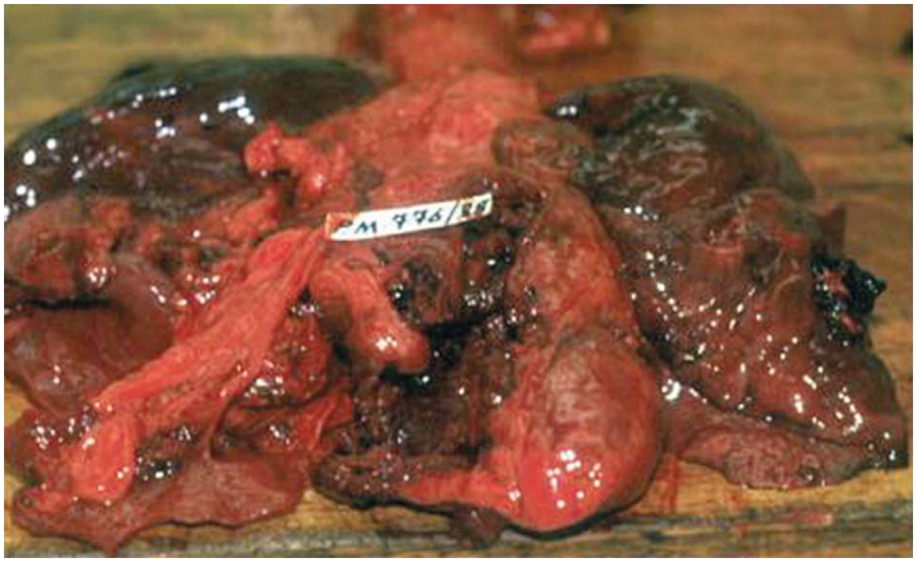

Figure 13 Mutilated heart from a high-velocity gunshot injury.

entrance profile widens, the drag on it increases, and it may also tumble.

The tendency for bullet deformation and fragmentation is an intended feature of the bullet by virtue of its physical makeup, and the bullet is fashioned for this effect by the manufacturers of ammunition. Bullets with a rounded or blunt configuration of nose will have a greater amount of drag and impart more energy and damage to tissue than bullets with a pointed nose. Bullets that distort at the nose, such as soft-point or hollow-point ammunition, creating a "mushroom" effect of deformation, also cause greater damage than pointed-nose projectiles. With increased velocity, bullets also tend to break up. This applies to soft-point and hollow-point rifle bullets especially, and it is generally not seen with handgun velocities. Shrapnel fragments will then be secondary missiles that create their own tracks and increase damage. In addition, certain types of pointed, full-metal-jacketed (military) rifle bullets are also designed to fragment extensively. For example, the 5.56-mm round fired by the R4 and R5 rifles in South Africa causes exceptionally severe wounds due to its velocity and tendency, due to yaw, to break up from the base, extruding and dispersing its lead core, as it compresses out along its length and bends at the cannula, with the pointed tip remaining intact with lodgment or exit (Figure 14).

Density, elastic cohesiveness, and recoil to injury of different tissues vary and affect the extent of wounding. Generally, physical disruption of tissue occurs when the limits of elastic accommodation to deformation are exceeded. Skin has great elastic ability but is easily punctured by a bullet, leaving a small perforation. Muscle is of good density and also has remarkable elastic recoil and cohesion, and the permanent wound track remains small. Lung tissue has low density and is exceedingly elastic, suffering less permanent destruction of tissue. Liver and kidney, on the other hand, are dense tissues, but with less tissue suppleness and cohesiveness, and suffer the consequences of wider and greater damage.

Figure 14 Bullet fragments of a 5.56 $\times$ 45 round extracted from a body.

Effects of Intermediary Obstructions

Bullets may strike solid intervening structures or surfaces and then enter a body, either having passed through the structure or deflected off it. A bullet ricochets (bounces) upon impact on a surface at certain critical small angles of approach, with the outcome determined by velocity and physical characteristics of the bullet and also the nature of the surface struck.

Ricocheting bullets are unstable, erratic, and unpredictable, and they may tumble, producing irregular and atypical entrance wounds, tending to lodge in the body. A bullet may also show a flattened side from first impact. Portions of the body surface adjacent to or on the surface struck by the bullet may show a shower of punctate abrasions due to fine fragments of surface and missile; examples of these may be seen with a ceramic tiled surface, or tarred or concrete pavement surface. This appearance may be mistaken for gunpowder "tattooing" abrasions, but they are usually larger, irregular, and coarser than true tattooing. Intermediate targets may also include glass, wood, and clothing/fabric.

Path through the Body

A bullet passing through the body tends to retain its original direction, except when at sufficiently low velocity to ricochet off bone. In the cranium, for example, a bullet may ricochet off the base of the skull, deflecting upward into the brain at another angle.

Wounds from Shotguns

Shotguns differ from rifled weapons in that they discharge a cluster of pellets, which begin to disperse after a short distance and fan out as multiple single projectiles. At close distances, injuries can be devastating due to the effects of multiple pellets. Because of poor aerodynamics, the pellets do not reach the distances that bullets do and lose velocity rapidly, being much less effective at longer ranges. In addition to the constituents of a conventional rifled gun discharge, wadding (plastic, cardboard, or felt "spacers" between propellant and pellets in the cartridge) and sometimes fragments of the cartridge case may also emerge from the muzzle, causing injury at close range. The appearance of the cluster of pellet wounds varies greatly with firing distance and helps to establish such range of fire. Rare usage of shotgun slugs may produce severe wounds due to missile size.

Consequences of Gunshot Injury

The course and extent of the missile track and whether or not vital structures are hit are very significant factors that determine the degree of injury, apart from the quantity of energy transfer. Serious wounds may still occur with low-velocity bullets, which can injure vital organs. The manifestations of wounds also depend on the type of projectile (deforming or nondeforming types, small pellets, large slugs) and the type of tissue. With shotguns, the severity of wounds depends mainly on the distance from the shooter. Gunshots are also likely to be contaminated.

Effects on Skin

Skin is tough because it is resilient and elastic, and it is more resistant than muscle to injury and perforation. The minimum velocity required by the projectile to perforate the skin ranges from $58\,\mathrm{m\,s^{-1}}$ for a .38-caliber lead handgun bullet to $101\,\mathrm{m\,s^{-1}}$ for a small lead airgun pellet. Lighter projectiles need higher velocity for penetration. Velocity lost in perforating skin alone is less than that required to pass through muscle tissue bulk.

Effects on Bone

Bullets cause fractures and often fragmentation, thrusting bony fragments forward in the direction of the track, that then act as secondary missiles. The appearance of a fracture may help to establish the direction of the track because the bullet levers (bevels) out the edges of the bony shelf around the perforation on the exit side, creating a cone-shaped excavated appearance and a neat "punched-out" hole on the entry side. This is best seen in the skull, due to its double layer of compact bone with a sandwiched inner spongy layer of diploe. Skull bone defect characteristics also help to establish the nature of oblique and tangential shots (keyhole and gutter types). Another phenomenon seen with high-energy gunshots of the skull vault (particularly with contact wounds) is remote fractures of the base, especially at the orbital plates, due to cavitational and expansile pressure waves in the rigid cranium (Figure 15).

Effects on Internal Tissues

With low-velocity wounds, wounding is caused by laceration of tissues along a wound track. The seriousness of wounding depends on the importance of the damaged structure to sustaining life (e.g., the heart and great vessels, major air passages, and vital brain centers) and on the rate and degree of bleeding. High-velocity wounds are accompanied by widespread damage due to cavitation, especially in solid organs such as liver and brain.

The wound track through the brain may be wide, with surrounding tissue contusion at both entry and exit sites and along the track. Contusions may also be seen on the entire basal brain surface overlying basal skull bone irregularities and prominences. Fine bone splinters dispersed along the brain track adjacent to the entry wound may also help establish the direction of the track in uncertain cases. Deaths from gunshot to the brain are usually due either to vital center injury or, if the individually briefly survives, to complications of increased intracranial pressure and other extracranial sequelae (Figure 16).

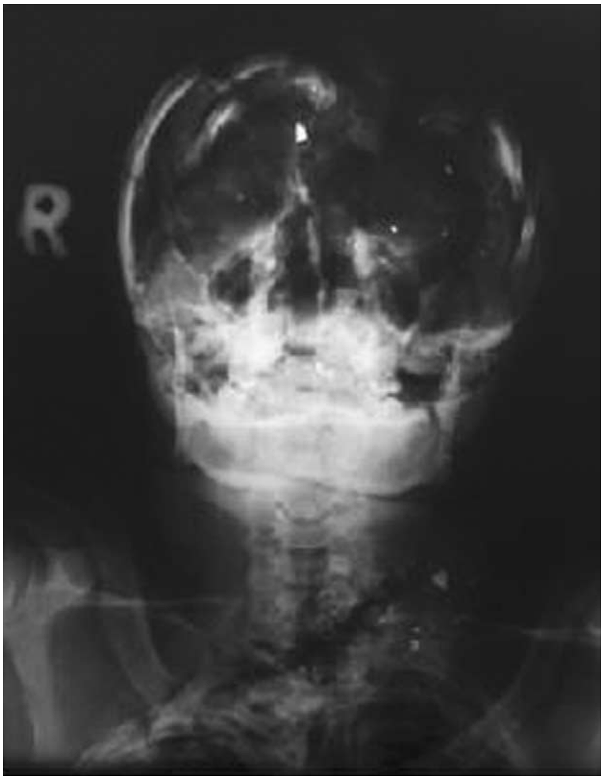

Figure 15 X-ray showing high-velocity gunshot of the head with explosive effect and another wound obliquely across the cervicothoracic spine.

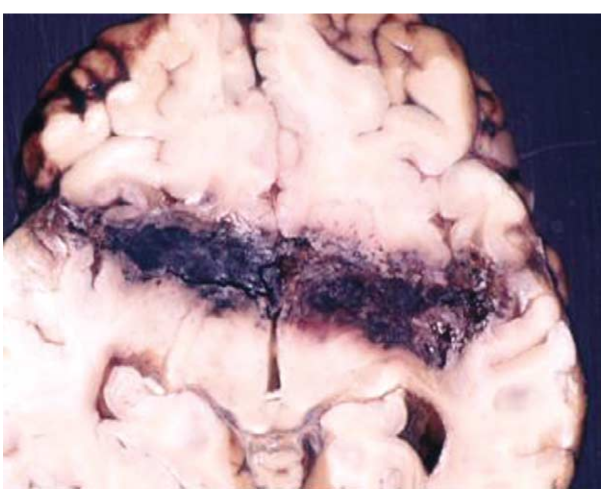

Figure 16 Gunshot wound track through the brain.

Morbidity and mortality from delayed complications of abdominal gunshot wounds, especially those involving the bowel, are high, due to rapid contamination and blood stream dissemination of sepsis.

Ability to Act after Rapidly Fatal Injury

It is often relevant in legal proceedings to know if someone who died from injuries was immediately killed or incapacitated; if not, what type of activity was possible, and for how long? The period of survival and ability to act are not the same. The subject is fraught with difficulty due to unreliability of reported time periods and physiological variability between individuals. Any two people suffering identical injuries may differ in their capabilities to act and survive.

Aside from age, fitness, and preexisting disease, the nature of injury is relevant. Reported cases show that individuals sustaining serious gunshot wounds are capable of extraordinary actions in the several seconds before they collapse and die. With an extensively lacerated heart or severed large artery, an individual can retain consciousness for at least 10–15 s before oxygen remaining in the cerebral capillaries is depleted. In addition, with gunshots of the brain, victims with severe frontal lobe wounds may have prolonged survival periods, while wounds of the basal ganglia may result in immediate unconsciousness and incapacity. Although severe brainstem wounds usually result in immediate unconsciousness, incapacitation, and death, there have been a few reported cases of short survival in a vegetative state.

The issue of "stopping power" of a bullet is also relevant. It is believed that deforming and expanding bullets are more able to incapacitate. Although they may theoretically produce worse internal injuries than nondeforming ones, trauma surgeons and pathologists are unable to distinguish between these appearances. Stopping power is more likely a characteristic of the type of vital organ or structure injured than the degree of damage sustained.

Firearm Discharge Residue

Discharge of a firearm is accompanied by heated gases and flame for a very short distance, soot, unburnt or burning powder particles, primer residue, fine vaporized metal from the bullet or cartridge case, and fine metal particles stripped from the bullet. Soot and powder particles carry for slightly longer distances than the other constituents. Determining the range of fire from the varying configurations in wounds of these types of residue is a critical part of wound evaluation.

The detection of gunshot residue from wounds, clothing, hands of the victim, and suspected shooter is a specialized forensic ballistic examination. Meticulous and timely collection of evidentiary material is important (Table 3).

Table 3 Firearm discharge residue

Source	*Major constituents*
Primer	Lead, antimony, barium
Powder	Nitrocellulose, nitroglycerine
Bullet	Lead, copper, iron
Cartridge	Copper, zinc, nickel
Barrel	Iron, oil

Modern methods of laboratory analysis of primer residue (barium, antimony, and lead) include flameless atomic absorption spectrometry and scanning microscope–energy dispersive X-ray spectrometry. Trace metal detection techniques are used to link the use of a particular weapon with an individual, and they rely on trace metal residue remaining on the palms after gripping a gun. Soot and powder deposits seen on clothing or wounds with the naked eye, magnification lens, or microscope by an experienced pathologist are usually sufficient to make a finding of range of fire. Laboratory analytical tests for nitrites produced by the burning of smokeless powder (cellulose nitrate) and for the detection of lead residues are available.

Value of the Scene Examination

As with all suspected homicides and other cases in which uncertainty and/or suspicion prevail, a visit to the scene by the pathologist or forensic practitioner is particularly important in the case of gunshot fatalities.

The scenario is often critically dissected out in subsequent court hearings in which range of fire, intermediary obstructions, disturbances of the scene, direction of fire, patterns of blood splatters, and amount of physical activity following injury relating to the degree and position of significant lost blood are considered. In addition, positions of the firearm and cartridge cases ejected (particularly in suspected suicidal gunshots of the head) in relation to the body and the number of shots fired, among other issues, may be debated. A scene examination places the medical examiner in a far superior position to express critical opinion.

Autopsy on the Gunshot Victim

The postmortem examination on the gunshot victim should be as meticulous as any standard forensic autopsy examination. Prerequisites include a good circumstantial history of the case up to and near the time of the death and a scene examination where possible. Particularly important is the careful examination of clothing, radiography, photography, and skillful collection of gunshot residue (in correct receptacles). For optimal evaluation of wound detail, good light, preferably natural, is crucial.

Value of Radiography

Radiography is an invaluable tool in gunshot autopsies, and it should be mandatory. It indicates not only the location of lodged missiles but also the nature of the dispersion of bullets and shrapnel fragments, where fragmentation and deflection occur, and the pattern of the bony injuries sustained. Imaging may either be by plain film radiography or by fluoroscopy, and a permanent record may be obtained either by plain films or by thermal-type prints for legal purposes. Two film views at right angles to each other are necessary for precise location of a missile. Radiography is equally important when an exit wound is present, contrary to some common perceptions, because an exit wound may lead one to believe that the entire missile has passed through, whereas a bone or bullet fragment may have exited and the evidence-bearing bullet or fragment may still be lodged internally. This may be easily missed at autopsy if X-ray examination is not done beforehand (Figure 17).

Unusual consequences, such as bullet embolism, may require radiographs of peripheral and remote regions.

Miscellaneous Considerations

Manner of Death

The distinction between murder, suicide, and accident is of prime importance in any firearm death and may be complex. It requires consideration of complete circumstantial history, witness statements, scene examination, and autopsy, ballistic, and other laboratory evidence. There is no known distinguishing manifestation of a gunshot wound that proves a specific manner of death.

Suicide by Firearm

Most suicides occur with handguns, and in males, and most are of a contact nature. These are usually inflicted into the head (80%) but may also involve the chest (17%) or abdomen (2%). Wounds of the head may be bitemporal or intraoral, but they may vary with regard to position. Appearances may also vary with sex or handedness of the deceased. Although suicide patterns of wounds are recognizable, there are no absolutes and many variations occur. Victims have shot themselves at intermediate and greater ranges and in uncommon places on the body, including the back of the head, and even multiple gunshots are seen. Some cases may be difficult to distinguish from accident and homicide. Discovery of a body may reveal a gun still held in the hand or otherwise close to the body. The firing hand (and

Figure 17 X-ray, high-velocity missile. The X-ray shows the appearance of a high-velocity gunshot wound of the right thigh with only soft-tissue injury caused by the 5.56×45 military round (M16 or R4/R5 rifle). The typical fine shrapnel fragments of the lead core of the bullet provide the ''snowstorm'' appearance and crimping of the bullet with the characteristic ''bent triangle'' of the bullet tip. A, fine shrapnel fragments; B, bullet head.

even the firearm muzzle) may show a "backsplatter" of fine blood droplets, which occurs more often with higher-caliber gunfire. This may also be seen on the other hand if it was used to support the barrel. The absence of such blood splatter does not preclude a contact wound.

Wounds from Homemade Firearms

Characteristics of homemade gun wounds include extensive soot deposits and burns in very close and contact wounds, atypical muzzle imprints, and lacerations of the firing hand. In addition, there is reduced depth of incursion into the body by the bullet, which shows the absence of typical rifling marks.

Accidents by Firearm

In addition to a pathologist's consideration of the nature and positions of wounds and information from reconstruction of scenes, the evaluation of the functional state and safety characteristics of a firearm (including its capability to discharge when dropped or with very light trigger pressure) is a technical matter within the ambit of a firearms examiner.

Gunshots Involving the Gravid Uterus

These are not uncommon, and effects include miscarriage, premature delivery, or intrauterine death, although maternal deaths are rare.

Hunting Accidents

Hunting accidents are frequently associated with negligent handling, careless behavior with weapons, and disregard for basic issues of safety.

Armed Conflicts and Civilian Shootings

In armed conflict, the number of people wounded is normally at least twice the number killed. In situations in which international codes governing warfare are not adhered to, as in extrajudicial executions of prisoners or civilians, the number killed may be greater than the number wounded when shots are fired against persons or a group who are immobilized, in a restricted space, or incapable of defending themselves. Victims may be shot from closer distances and sustain multiple shots in vital regions from automatic weapons, increasing the probability of fatal injury. This distinction may have significance for the recognition of war crimes.

Lead Poisoning from Retained Bullets

This is a rare complication, occurring mainly when a bullet lodges in a joint space, with the synovial fluid appearing to promote the dissolution of lead and entry into tissues.

Embolism of Projectiles

This is an occasional phenomenon, usually suspected when there is no exit wound and no bullet visible on X-ray, or none is retrieved during exhaustive examination of the region expected to contain the lodged missile. Cases usually involve gunshot entry wounds of the chest and abdomen. The bullet is usually of smaller caliber and of low velocity, having insufficient penetrating ability. If entering the left side of the heart, thoracic aorta, or abdominal aorta, it usually embolizes into the femoral and popliteal arteries of the lower limbs; occasionally, pellets have embolized to the brain. In the case of less frequent venous embolism, bullets may enter the right side of the heart, inferior vena cava, or iliac veins, with retrograde passage either to veins of the lower limbs or upward to the heart. Nonvascular "embolization" or migration of bullets along tissue planes, body cavities, flat and curved bone surfaces, air passages, and sinuses has occasionally been reported.

Pistol Whipping

This refers to blunt assault using the butt of a firearm, usually to the head or face but also to the body.

Bullets in Free Fall

Injuries, including penetrating wounds of the head, have been caused by bullets falling downward to the ground after having been shot into the air, particularly in festive times and at celebratory events, such as on the eve of a new year. The velocity of the free-falling bullet may increase to beyond the minimum level for skin penetration.

Rubber and Plastic Bullet Injuries

Developed within the past three decades for police riot-control purposes, rubber and plastic bullets are intended for firing distances of not less than 20–30 m and to cause pain and minor incapacitating injury only. Many injuries, and a number of deaths, have since been reported.

Blank Cartridge Injuries

Used in starter pistols for athletic races, blank cartridges are intended for audible detonation only and do not fire a bullet or pellet because the cartridge contains only detonating powder. However, if discharged with the muzzle in contact with the body, especially at the chest and abdomen, fatal injuries may ensue.

Ballistic Identification

Ballistic identification is another function of the ballistic examiner or firearm identification expert. Ballistic identification deals mainly with the comparison of fired bullets and/or cartridge cases with firearms to ascertain whether a bullet or cartridge case was fired from a particular gun. To do this, the rifling marks on fired bullets found at a crime scene are evaluated by microscopy in comparison with those on control bullets fired in the laboratory from the firearm in question. Cartridge cases are compared to fired control cases by firing pin impressions on the base and other various ejector, extractor, magazine, and breechblock markings. It is important to use the same brand and type of ammunition in the testing. Other related examinations include comparison between fired bullets and between fired cartridge cases. Bullets are compared according to their class (type, caliber, and rifling marks) and individual characteristics (scored on the bullet shoulder as it passes through the barrel).

Fingerprints may sometimes be obtained from a gun, and often they can also be obtained from fired cartridge cases. Tissue and blood trapped on a bullet or bullet fragment, having passed through a body, may be subjected to histological or cytological examination to establish the tissue or organ perforated and for DNA "fingerprint" analysis to identify the victim.

Chain of Custody of Specimens

Ensuring the continuity and legal acceptability of all evidence is a critical aspect of forensic and ballistic examinations, and it includes the correct handling of bullets so as not to deface or mark them in a manner that spoils evidence.

Surgical Management of Soft-Tissue Gunshot Wounds

Low-velocity soft-tissue injuries are amenable to conservative, local treatment. Contamination is not severe, and fractures are treated conventionally, dictated by the nature of bony injury. In high-velocity and other severe injuries, extensive tissue destruction, devitalization, and gross contamination necessitate open surgical management, debridement, irrigation, and antibiotic cover.

See Also

Imaging: Photography; **Injury, Fatal and Nonfatal:** Firearm Injuries; **Injuries and Deaths During Police Operations:** Shootings During Police Stops and Arrests; **War Crimes:** Pathological Investigation

Further Reading

Bartlett CS (2003) Clinical update: Gunshot wound ballistics. *Clinical Orthopedics* 408: 28–57.

Centers for Disease Control and Prevention, National Center for Health Statistics (2001, September 21) National vital statistics reports, deaths: final data for 1999, vol. 49, no. 8. Available online at www.cdc.gov/nchs/fastats/firearms.htm.

Dada MA, McQuoid-Mason DJ (eds.) (2001) *Introduction to Medico-Legal Practice*, pp. 205–222. Durban, South Africa: Butterworths.

Di Maio VJM (1999) *Gunshot Wounds: Practical Aspects of Firearms, Ballistics and Forensic Techniques,* 2nd edn. Boca Raton, FL: CRC Press.

Fackler ML (1996) Gunshot wound review. *Annals of Emergency Medicine* 28(2): 194–203.

Knight B (1996) *Forensic Pathology,* 2nd edn. London: Arnold.

Krug EG, Dahlberg LL, Mercy JA, Zwai AB, Lozana R (eds.) (2002) *World Report on Violence and Health*. Geneva: World Health Organization.
Matzopoulos R (ed.) (2002) *A Profile of Fatal Injuries in South Africa, 2001*. Third annual report of the National Injury Mortality Surveillance System. Cape Town, South Africa: Medical Research Council.
Peden M, Meumann C, Dada M (1998) Homicide in Durban. *Trauma Review* 6(2): 7–8.
World Health Organization (2001) *Small Arms and Global Health*. Contribution to the United Nations Conference on Illicit Trade in Small Arms and Light Weapons, July 9–20. Geneva, Switzerland: WHO.

Ballistic Trauma, Injuries *See* **Injury, Fatal and Nonfatal:** Explosive Injury; Firearm Injuries; **Tactical Medicine**; **Terrorism:** Suicide Bombing, Investigation; **War Injuries**

Bioterrorism *See* **Terrorism:** Nuclear and Biological