Air Medical Journal 42 (2023) 80–85

Contents lists available at ScienceDirect

Air Medical Journal

journal homepage: http://www.airmedicaljournal.com/

Critical Care Update

Guns, Bullets, and Wounds

David J. Dries, MSE, MD

Epidemiology

Feliciano DV, Mattox KL, Moore EE, eds. Epidemiology. In: *Trauma*. 9th ed. New York, NY: McGraw Hill; 2021:15-30.

https://www.cdc.gov/injury/wisqqars/overview/key_data.html

https://www.cdc.gov/injury/wisquars/fatal.html

Grinshteyn E, Hemenway D. Violent death rates: the United States compared to other high-income OECD countries, 2010. *Am J Med*. 2016;129:266-273.

Goolsby C, Schuler K, Krohmer K, et al. Mass shooting in America: consensus recommendations for healthcare response. *J Am Coll Surg*. 2023;236:168-175.

Haferteen SC, Davis JW, Townsend Sue LP, Kaups KL, Cagle KM. Myths and misinformation about gunshot wounds may adversely affect proper treatment. *World J Surg*. 2015;39:1840-1847.

According to data from 2016, there were approximately 39,000 intentional (98%) and (2%) unintentional gun-related deaths in the United States. These data represent 107 firearm-related deaths per day or 12 deaths per day per 100,000 population. Most firearm-related deaths among males 15 to 34 years of age in the United States (67%) were homicides. Suicide deaths from firearms have also been steadily increasing. Finally, the number of nonfatal firearm injuries has grown. In 2016, there were 116,414 reported nonfatal injuries due to firearms or 36 per 100,000 population. This represents an increase of 50% since 2010.

Firearm-related injuries disproportionately affect males (85%) and younger people. In the 15- to 30-year-old age group, the violence-related death rate for males is nearly 7 times that for females. Firearm-related injuries are the leading cause of death in black males 15 to 34 years old and are the third leading cause of injury-related death in those aged 10 to 84 years. Firearm-related mortality is 8 times higher in the United States than other high-income countries in the world.

There has been a significant increase in the suicide rate in the United States, with 50% of these events being firearm related. Suicide in people aged 65 years or older is a significant problem, representing 25% of all firearm-related injuries for both sexes and all ages. Over 90% of suicides in the elderly patient population were among men. These data reflect the presence of firearms of some type in approximately 30% of US households, including 46% of rural and 19% of urban residents. Outcome data suggest that those who live in homes with a firearm are more likely to die from homicide or suicide in the home than are residents of homes without firearms.

Another alarming recent trend is the increase in the number of mass shootings throughout the United States, which leads the world in this problem. Recent terror-related mass shootings have stimulated public debate over access to weapons designed to inflict multiple casualties and social dilemmas contributing to this problem. Earlier reports suggested that the United States, which contains approximately 5% of the world's population, owns between 35% and 50% of its guns.

Despite data suggesting that gunshot wounds are an epidemic, the understanding of many health care providers regarding ballistics, bullets, and guns is limited because of the inaccuracy in the media, uneducated beliefs, and urban legends. A review of the fundamentals is in order.

Physics First

Kneubuehl B, ed. *Wound Ballistics: Basics and Applications*. 2nd ed. New York, NY: Springer; 2022:1-33.

Stephanopoulos PK, Pinialidis DE, Hadjigeorgiou GF, Filippakis KN. Wound ballistics 101: the mechanism of soft tissue wounding by bullets. *Eur J Trauma Emerg Surg*. 2017;43:579-586.

Volgas DA, Stannard JP, Alonso JE. Ballistics: a primer for the surgeon. *Injury*. 2005;36:373-379.

Ballistics, the science of bodies in flight, includes the physical triggers involved and the movement of the projectile. Based on the location of the projectile, ballistics is divided into several areas. Interior ballistics is the study of the acceleration of a projectile (think bullet) within a weapon after firing and the related processes. The domain of interior ballistics ends when the bullet leaves the barrel of the weapon. However, a weapon may continue to influence the flight of a bullet even after it leaves the barrel, such as through oscillations created during transit in the barrel or via gases that follow and overtake the bullet. The phase of motion for a bullet shortly after it has left the barrel of a weapon is known as intermediate ballistics. Exterior ballistics describes the time at which the bullet escapes the influence of the weapon to the moment at which it strikes its target. This portion of ballistics involves determining changes over time and space in the trajectory of the bullet, the velocity of the bullet, and the movement of the bullet about its center of gravity considering the various external forces acting on the bullet during flight. Terminal ballistics describes the phenomena occurring when a bullet penetrates living tissue or a nonliving object. If the bullet encounters a person or an animal, the effect is described as wound ballistics. Wound ballistics may be affected by the properties of interior, intermediate, and exterior ballistics. The effect of various types of ballistics in part depends on the distance between the muzzle releasing a bullet and the target. Not surprisingly, the structure of

1067-991X/$36.00

https://doi.org/10.1016/j.amj.2023.01.001

the bullet and the characteristics of the firing weapon also play a role. To understand what happens to a bullet in a living being, a basic understanding of the characteristics of tissue struck and the ballistics of firearms and ammunition are needed.

Wound ballistics examines the development of a wound channel in tissue and describes using physical models that include velocity and mass (factors required to determine kinetic energy), the resulting pathway created through tissue by a projectile or bullet, and the understanding we have gained of tissue injury through simulation of wounding. Although comments in this brief report will focus largely on the effects of handgun and rifle bullets, I will include some comments on the wound ballistics of fragments as may occur in explosive attacks or contact with shotgun pellets. Comments relative to fragments, as from an explosive or shotgun, are very appropriate because these weapons have been noted as a frequent cause of injury in armed conflicts and in bombing episodes.

Several physical terms are relevant to the description of the motion of a projectile. Kinematics describes the path or trajectory of a projectile. The most important parameter in kinematics is velocity, which considers the speed and direction of the projectile. Simply put, acceleration occurs if the speed of a projectile in a particular direction increases, and deceleration takes place if the speed of an object in a particular direction decreases. Some projectiles will change velocity (describing the speed and direction of the bullet or projectile) multiple times during the course after leaving a weapon. At times, a change in velocity may reflect gravity or atmospheric conditions. Obviously, contact with tissues or solid objects may have a significant impact on the velocity of a projectile. Wounding caused by a projectile takes place when energy is transferred to a tissue or other solid object struck by the bullet or other projectile. Energy transfer by a projectile may be expressed as a function of the mass of the projectile and velocity. For example, one can visualize the change in speed and direction of a bullet when tissue is struck. A wound occurs when energy is converted to work performed on tissue struck by the projectile.

To generalize, materials involved in wound ballistics, such as the type of tissue or materials used to simulate tissue, act on a bullet in a manner similar to that of a viscous or thickened liquid. The behavior of a bullet in tissue depends to a significant degree on the impact conditions. Impact conditions are linked to the movement of the bullet in air before contact with tissue. Thus, the mechanics of fluids and gases play a role in wound ballistics. The motion of a bullet or other projectile in a liquid or gaseous medium generates heat whether through friction or as a result of subjecting gas or liquid to increased pressure.

Temperature is 1 of the essential parameters used to describe a process that involves energy transfer. Temperature reflects the thermal state of a projectile and is a measure of energy of the materials making up the projectile. Temperature is independent of the mass of a bullet or other projectile. If the temperature of a material changes, physical characteristics such as dimensions, color, or electrical conductivity may also be affected. An increase in temperature indicates that the energy content of the material under consideration has been increased. Contact with heated material is an obvious means to transfer energy from the material to a tissue or other solid object.

Interaction with tissues defines the process of wounding by bullets or other projectiles. Obvious tissue changes include the disruption of tissue and deceleration with deformation of the missile from tissue resistance. The resultant wound may penetrate or perforate depending on whether the bullet is retained in the tissue or exits the body. The interaction of projectiles and tissues is considered at 2 sites, the central area of complete tissue destruction along the path of the missile or permanent cavitation and the surrounding area briefly distended by the passage of a missile or temporary cavitation. Both areas of injury contribute to the final appearance of the wound. The visible track left by a bullet or other projectile filled with fragmented tissues, blood clots, and possibly foreign material characterizes permanent cavitation, which is also called the wound channel. This permanent track has also been referred to as the permanent cavity. A penetrating projectile crushes the tissue part sustaining impact from the leading edge of the bullet or other missile as the result of excessive pressure created in the immediate vicinity of contact with the high-velocity projectile. Pressure at the leading edge of the missile or projectile contact is estimated on the order of thousands of atmospheres. The destructive effects from excessive pressure should not be separated from immediate tissue disruption caused by movement of a missile, which has been termed prompt or rapid damage. The phenomenon of prompt or rapid damage is a typical mechanism of direct tissue injury from wounds produced by handgun bullets. In addition, supersonic projectiles, particularly those penetrating at velocities above 600 m/s (the common threshold for high-velocity weapons), generate 2 types of potentially harmful pressure changes: a shock wave from the intensity of the impact and cavitation (described earlier), which may not be limited to high-velocity penetration but is significantly greater than a concussive wave produced by a lower-velocity handgun bullet. Ultimately, the decisive factor in gunshot wounds with respect to morbidity and mortality remains the location of the injury and its anatomic relationship to vital organs and major vessels.

Ammunition

Hanna TN, Shuaib W, Han T, Mehta A, Khosa F. Firearms, bullets, and wound ballistics: an imaging primer. Injury. 2015;46:1186-1196.

Rhee PM, Moore EE, Joseph B, Tang A, Pandit V, Vercruysse G. Gunshot wounds: a review of ballistics, bullets, weapons, and myths. *J Trauma Acute Care Surg.* 2016;80:853-867.

Stefanopoulos PK, Pinialidis DE, Hadjigeorgiou GF, Filippakis KN. Wound ballistics 101: the mechanisms of soft tissue wounding by bullets. *Eur J Trauma Emerg Surg*. 2017;43:579-586.

The round, shell, or cartridge are common terms describing ammunition for a gun. Contemporary rounds consist of a casing, a primer, and propellant, with a projectile at the tip. The projectile is described by the selected material, the shape of the material, and if it has an outer lining or jacket. The nomenclature for a cartridge is variable and is often based on the unique characteristics of the cartridge. Variation in cartridge nomenclature is based on the country of use, the organization producing the round, and the system of measurement used to describe the size of the cartridge. For example, in the United States, the caliber or diameter of a round is measured in hundredths of an inch, whereas in the rest of the world, caliber is typically measured in millimeters. Contemporary ammunition typically has a brass casing with a primer that ignites upon impact with a firing pin producing a small explosion. This in turn causes the smokeless powder in the cartridge to burn very quickly, thus producing pressurized hot gas, which propels the projectile or bullet down the barrel of the gun and out of the muzzle or open end of the barrel. The casing, which contains the propellent for the round, is typically made from brass, steel, aluminum, or plastic as in the case of a shotgun shell. The propellant is a smokeless gunpowder, and the projectile or bullet fits tightly at the tip of the casing, which contains the propellant. Specifications for the casing include the overall size, length, body diameter, rim type, casing body tapering, bullet weight, and caliber. These specifications are particular to each cartridge. Cartridges are available in various sizes or shapes but commonly are

cylindrical and taper toward the tip of the cartridge. Located opposite the projectile or bullet at the proximal aspect of the shell, the primer is a type of blasting cap that ignites the smokeless gun powder within the casing when struck by a small metal firing pin. This initial impact causes a contained explosion resulting in rapidly expanding gases and propulsion of the bullet, which is located at the tip of the round, down the barrel of the weapon. The primer may be located in the center of the cartridge, at the tail of the cartridge, or at the edge of the cartridge tail. Cartridges having the primer located in the center of the posterior aspect are considered safer and more reliable. Cartridges with the primer centrally located in the back of the round can also withstand higher pressures without disintegrating.

The discovery of gunpowder was directly related to the evolution of firearms. The initial formulation of gunpowder was made from sulfur, charcoal, and potassium nitrate. This material was first used for the creation of fireworks. The explosive power of gunpowder was used in many ways but soon found its way into the creation of weapons. Primitive firearms date back to the 13th century. The Chinese developed early firearms intended to shoot a variety of objects, such as pieces of porcelain, darts, or arrows. The use of gunpowder rapidly spread throughout the Middle East and Europe. Gunpowder is the most important component of the cartridge that determines energy delivery. Gunpowder was difficult to use at first because it was dangerous. Early weapons using gunpowder released plumes of black smoke, creating a disadvantage for the shooter. Reloading of these early weapons was not efficient. As gunpowder formulations evolved, newer materials released less heat and smoke and generated more explosive force per gram compared with earlier preparations. As gunpowder became more effective, scientists developed the primer, which exploded with compression. The combination of gunpowder ignited by the primer led to the development of the modern cartridge.

The projectile, or more commonly called the bullet, is the part of the cartridge that exits the weapon firing the cartridge. Bullets come in a wide range of sizes and shapes. Bullet characteristics affect the kinetic energy imparted to a target tissue. Energy delivery depends on the speed and weight of the bullet as well as on the composition of the bullet. For example, the center of a modern bullet is typically made of soft lead, which is inexpensive, easy to work with, and readily available. Current bullets come in precise diameters, lengths, mass, shape, and outer jacket formulation. These factors determine the energy and tissue damage imparted to the target.

A bullet is often covered by a metal jacket typically composed of copper, nickel, or a steel alloy. A full metal jacket round typically refers to a bullet with a soft lead inner core where the tip and sides are completely covered by a thin metal. Full metal jacket bullets reduce vapor generation; thus, these are better suited for indoor firing. A full metal jacket bullet results in less expansion, fragmentation, and deformation of a bullet when the target is struck, reducing tissue injury. The design of the outer jacket on a bullet is essential to determining the magnitude of tissue injury and has been a focus of international conferences intended to standardize bullet design. The jacket is essential for a bullet designed to travel more than 2,000 ft/s to prevent deformity and melting from high temperatures in the barrel of a gun. In theory, a full metal jacket bullet has less expansion, deformation, and fragmentation, which will decrease the transmission of kinetic energy to tissues. A partially jacketed bullet deforms and fragments upon entering tissue, creating retention of bullet fragments and transferring more kinetic energy to the tissue because of the fragments retained, with the creation of more deformity and a larger wound.

Clearly, bullets are used in a wide variety of circumstances including civilian and police handguns, assault rifles, and various hunting applications. Handguns have semijacketed hollow point bullets at the tip of a round. On the other hand, military weapons are now designed to be fully jacketed in order to reduce the scope of tissue destruction. Historically, humanitarian declarations have prohibited the use of bullets that expanded or flattened easily in the body because of the magnitude of associated tissue injury. In summary, fully jacketed bullets retain their shape when traversing tissue. This reduces the transmission of energy to the affected tissues. Partially jacketed bullets are designed to expand upon entering tissue and deliver more of the kinetic energy carried to the target.

The shape of a bullet determines the behavior in flight, penetration of the target, and response of the bullet once the target is entered. Bullets with a pointed tip have an aerodynamic advantage. The “pointed” bullet has lower drag, decelerates less, and is more accurate because it is less affected by crosswinds and is more stable in flight. For rifle bullets, shape changes such as flattening of the nose may affect how the bullet behaves during flight and in tissues. Instability in flight is important because bullets tend to change pitch (ie, an upward or downward direction shift) or yaw (ie, movement to the left or right) with flight and after tissue penetration. If the bullet deforms and does not pass through the subject, the entire kinetic energy of the bullet is delivered to the target. One goal of transferring kinetic energy is in hopes of knocking down the victim or “dropping” them. The modification of bullets to increase wounding capacity is not a new concept. International convention has placed specifications on the use of bullets designed with increased wounding capacity in warfare for this reason.

Types of Weapons

Kneubuehl BP, ed. *Wound Ballistics: Basics and Applications*. 2nd ed. New York, NY: Springer; 2022:55-65.

Rhee PM, Moore EE, Joseph B, Tang A, Pandit V, Vercruysse G. Gunshot wounds: a review of ballistics, bullets, weapons, and myths. *J Trauma Acute Care Surg*. 2016;80:853-867.

Stefanopoulos PK, Filippakis K, Soupiou OT, Pazarakiotis VC. Wound ballistics of firearm-related injuries-part 1: Missile characteristics and mechanisms of soft tissue wounding. *Int J Oral Maxillofac Surg*. 2014;43:1445-1458.

Contemporary firearms are available in a variety of shapes and sizes. They may be classified based on the caliber or outer diameter of the projectile used with the gun and the type of mechanical action, such as revolver, semiautomatic, automatic, bolt, muzzle loader, and more. Guns may also be traditionally classified as firing low- or high-velocity projectiles or bullets. Handguns are considered low-velocity weapons, whereas most rifles are considered high-velocity firearms.

Handguns are designed to be handheld. They are concealable compact weapons intended for self-defense. Three common types of handguns are revolvers, semiautomatic handguns, and single-shot pistols. Single-shot pistols hold only a single round of ammunition and must be reloaded after each firing. These handguns have largely been replaced by revolvers. Revolvers have a rotating cylinder containing multiple chambers, each holding 1 round, which are capable of firing multiple rounds after loading of the chambers of the cylinder. Revolvers also have 2 general mechanical types: single action and double action. The single-action revolver requires the hammer, which fires a round, to be pulled back against a spring with the thumb. Pulling the trigger, the second action, releases the spring and hammer to fire the bullet. Each time the hammer of the revolver is cocked, the revolving cylinder realigns itself to the next chamber and is ready to fire the next round. A double-action revolver enables the shooter to pull the trigger, which cocks the hammer and fires the gun, performing the

double action with just 1 pull of the trigger. Thus, a contemporary double-action revolver allows all 6 bullets to be fired with only 6 tugs on the trigger. The classic single-action revolver requires cocking of the hammer between each pull on the trigger. Revolvers have a simple design, have fewer moving parts, and are more reliable compared with semiautomatic handguns.

Semiautomatic pistols are a third group of handguns having a single fixed firing chamber located at the rear of the barrel and a magazine that allows discharge of multiple rounds without the requirement for reloading after each round. Manual chambering occurs before firing the first bullet, which is stored in a magazine or clip. A standard magazine can hold 7 to 17 rounds stacked one on top of the other with a spring to push the rounds upward into the firing chamber when the chamber has emptied. When the trigger is pulled, the hammer strikes a pin, which contacts the primer of the round. With firing, the bullet is propelled down the barrel, and the hammer is again cocked with ejection of the shell from the fired round and loading the next round into the firing chamber. With a semiautomatic handgun, all rounds in a magazine can be fired as rapidly as the trigger can be pulled until the rounds in the magazine are spent. High-capacity magazines hold 10 rounds or more. In the United States, magazines typically hold 7 up to 17 rounds. Some high-capacity magazines hold up to 30 rounds.

Unlike the pistol, a compact firearm, long arms are the category of firearms with a longer barrel. These weapons typically are fired using both hands and are braced against the shoulder or hip. The barrel commonly ranges between 10 and 36 inches in length and is mounted on a stalk of wood, plastic, or metal, which provides a grip for stability while the operator is firing the gun. Long arms allow the user more handgrips because of the longer barrel and stalk with greater stability while aiming at a target in comparison to handguns. The most common types of long arms are rifles and shotguns.

The rifle is a type of long arm with a helical groove or distinct pattern of grooves, described as rifling, cut into the walls of the barrel. Because of this pattern of grooves, the term rifle was coined for this design of a long arm. Within the barrel, a rifle has raised areas of rifling commonly called lands. After encountering a projectile, lands impart a spin to the projectile around an axis corresponding to the orientation of the barrel of the rifle. This orientation provides stability to the projectile in space and minimizes tumbling or deviation from the intended ballistic path. Thus, rifling allows for additional range and accuracy of this long arm.

Rifles come with single-shot or bolt action mechanisms and semiautomatic or automatic mechanisms. Traditional hunting rifles are loaded at the breech or firing chamber and are reloaded with each shot. Newer hunting rifles and sniper rifles typically have bolt action. The bolt of these newer rifles includes a handle that is lifted to allow easy exposure of the firing chamber. A round can be placed into the chamber either manually from above or from below with the use of a magazine holding rounds in a stacked fashion. Each round fired requires a manual process of reloading by the operator pulling the bolt back, which also cocks the rifle in preparation for firing with a short pull of the trigger. Hunting rifles are designed to kill a large target animal with a single shot; thus, the ammunition is relatively large compared with handgun ammunition. Muzzle loading rifles are single-shot long arms usually with a bullet loaded via the end or muzzle of the barrel.

The semiautomatic rifle, like the semiautomatic handgun, uses recoil from the fired round to load the next round into the chamber for firing. The semiautomatic rifle fires a round each time the trigger is pulled until the magazine or clip is empty. Assault rifles are semiautomatic or fully automatic. An assault rifle is generally shoulder fired; uses cartilages in a clip or magazine; and may have selective fire between semiautomatic, automatic, or even burst triggering, which typically rapidly releases 3 rounds. Burst fire was developed to save ammunition because in typical practice only the first 3 rounds will strike near the intended target because recoil moves the aim of the rifle away from the intended line of fire. A machine gun typically refers to an automatic rifle that has a magazine or ammunition belt feed. This rifle will fire continuously if the trigger is pulled and stops when the trigger is released or rounds in the magazine or on the belt have been expended. A submachine gun is an automatic, magazine-fed weapon that is typically larger than a handgun but shoots handgun rounds. The effect of being shot with a submachine gun round is similar to being shot with a handgun projectile.

Shotguns are a smooth bore long arm firing a variety of projectiles ranging from small spherical pellets or bird shot to larger spherical pellets or buck shot and solid lead projectiles or slugs. Shotguns have an external appearance similar to rifles but differ in the lack of rifling inside the barrel. Some shotguns have a pair of barrels mounted next to each other as in a double-barreled shotgun. Shotguns may use breech loading in which rounds are directly loaded into the firing chamber; a pump where rounds are ejected and the weapon rearmed from a magazine with a pump motion of a forearm mechanism; lever action, which works like a pump shotgun but uses a lever to extract and chamber shells; and semiautomatic varieties. Shotguns are rated by the number of lead balls of equal size making up 1 lb. For example, a popular hunting weapon is the 12-gauge shotgun, which has a bore diameter equal to the size of 12 lead balls that add up to 1 lb. As the gauge of the shotgun increases, the caliber of the barrel decreases. The most commonly used shotgun shell is bird shot, containing many small lead pellets in each round. A popular form of buckshot contains 9 pellets, with each pellet having the potential for wounding equivalent to a small handgun round. On the other hand, a slug is 1 large projectile.

Tissue injury from shotguns is dependent on the kinetic energy of the shotgun shell with contained pellets and the distance between the weapon and the target. When shotgun rounds are fired at close range, typically several yards, the pellets act as a single large projectile. These shotgun injuries may be devastating because of the amount of energy transfer. The energy of shotgun pellets is reduced dramatically over short distances. Compared with the energy measured at the muzzle, at 50 yd, this energy is reduced to approximately 30% to 50% of the maximum possible energy for delivery or even less when small pellets are used. Shotgun pellets are not aerodynamically efficient or stable. During intermediate-range shotgun injuries (3-7 yd), pellets will spread apart and no longer act as a single projectile. Typically, at this distance, the spread will be approximately 12 in, and fascial penetration with multiple solid organ and/or hollow viscous injuries are common. Longer-range shotgun injuries (ie, > 7 yd with bird shot) will present with many skin wounds over a large area such as the whole back or entire abdomen and chest but often do not penetrate the fascia.

A shotgun cartridge containing buckshot delivers a large amount of energy in comparison to a cartridge delivering a larger number of pellets of bird shot. Patients struck with buckshot should be thought of as having been shot multiple times with a low-velocity handgun. Most of these patients will have visceral injuries requiring surgery, and, in general, conservative management is not recommended. Commonly, shotguns are used for hunting fast-moving birds or smaller animals at medium range.

The Wound Profile

Kneubuehl BP, ed. *Wound Ballistics: Basics and Applications*. 2nd ed. New York, NY: Springer; 2022:321-333.

Rhee PM, Moore EE, Joseph B, Tang A, Pandit V, Vercruysse G. Gunshot wounds: a review of ballistics, bullets, weapons, and myths. *J Trauma Acute Care Surg*. 2016;80:853-867.

Coupland RM. *War Wounds of Limbs*. Oxford, UK: Butterworth-Heinemann; 1993.

Several statements can be made about the wide variety of wounds observed in the setting of bullet and fragment injury. The standard features of individual bullet wounds taken from Coupland and Kneubuehl are as follows:

1. There is usually a small entry wound if the bullet is stable in flight and is not designed to expand with impact.
2. There is rarely a large volume of tissue damage with a small entry wound.
3. Extensive tissue damage at the entry point most likely reflects ricochet of the projectile or impact of an expanding bullet or a close-range shotgun injury including contact with multiple pellets.
4. There may be no exit wound. If there is an exit wound, the size is variable.
5. The length of the wound track and the amount of tissue damage from a bullet are variable; this is influenced by the energy of the bullet and its construction.
6. Whatever the construction characteristics of the bullet, an x-ray of the wounded body part commonly shows small metal fragments.
7. For individual fragment wounds, the wound track is widest at entry corresponding to the greatest amount of tissue damage.
8. The length of a wound track and the degree of tissue damage reflect the mass and velocity of the bullet or fragment causing the wound.
9. Fragmentation weapons frequently cause multiple wounds. The number of wounds is determined by the type of weapon and the proximity of the target struck to the source of the fragments. Fragment wounds may also be associated with blast, burn, or crush injuries.
10. When a projectile (think of a bullet) passes through tissue at high speed, the bullet does work on tissue, but the tissue also does work on the bullet. This explains bullet deformity and fragmentation, which may be seen in wounds.

Final general comments may be made from Coupland and Kneubuehl. First is that projectiles may cause a variety of wounds. Second, there may not always be significant tissue damage along a wound track. The amount and character of damage are a function of the construction of the missile and interaction of the missile with the targeted tissue. Third, tissue damage in a wound is frequently not uniformly distributed along the wound track. Finally, simulation materials, such as gelatin blocks, allow examination of real and simulated wound tracks, suggesting that they are similar. Overall, the point of maximum energy transfer in a simulated wound track corresponds to the point of maximal tissue damage in a real wound.

Rhee and coworkers provided an additional clinical perspective on tissue injury. Overall, the effective tissue injury depends on the kinetic energy (ie, the mass and velocity of the projectile); the distance from the muzzle to the target; and the dissipation of the kinetic energy, which depends on whether the bullet is retained or passes through the tissue encountered. Skin and lung have low density with greater elasticity and are less injured compared with muscle, which has greater density and less elasticity. The liver, spleen, and brain have far less elasticity than the lung and are much more severely injured in comparison with the lung by a bullet of comparable energy. Fluid-filled organs such as the bladder, heart, great vessels, and bowel transmit kinetic energy to a greater degree, and energy transmission may result in bursting of the organ. Bullets usually cause fragmentation or fractures of bone because bone has minimal elasticity and, if struck, may produce secondary fragments that act as other missiles, resulting in injury to adjacent tissues.

Bullets frequently do not follow a perfect straight line to a target. Rotational forces or tumbling move the bullet off a direct path of flight. If a bullet varies from a direct path to its target, a larger area of contact with tissue is created with greater tissue injury. In general, bullets do not tumble when the skin is pierced, but high-energy rounds may begin to tumble as energy is delivered upon travel through deeper tissues. High-energy projectiles become unstable as they decelerate. The energy of the bullet is then absorbed by surrounding tissue, causing stretching and tearing of the tissue. In contrast to high-velocity rounds, handgun bullets travel in a relatively straight line and will either traverse tissues in a straight line or make a limited turn if a bone is struck, in which case the bullet will typically shatter. The character of lacerations created by the bullet injury is dependent on the deformation of the bullet occurring when the bullet slows upon contact with the tissues.

A bullet with sufficient energy will create a cavity in addition to a penetrating wound track. As a higher-energy bullet passes through tissue, space left by the initial tissue injury forms a cavity from a pressure wave, typically from a high-velocity bullet, which forces tissues away, creating a gap in tissue similar in size to the bullet. In a temporary cavity, sometimes a space many times larger than the bullet itself is left, which will then collapse; this is termed temporary cavitation. Organs such as the liver, spleen, kidney, and brain are more likely to split or shatter because of the development of temporary cavitation. Skin, muscle, and intestine absorb energy and are more resistant to the development of temporary cavitation. If the muzzle of the weapon is close to the skin, gases from the explosion of propellant gunpowder can be blown into adjacent tissue, causing additional cavitation with tissue expansion. High-velocity rounds are more likely to have significant cavitation injury. In general, the more solid and less elastic a tissue, the more profound cavitation is. For example, an injury to the thorax will have less cavitation than an injury to the liver. Injuries to the thorax with severe lung injury, when seen, are typically caused by secondary missiles created by the bullet impact with shattering of the ribs or vascular injury with bleeding around the bullet track.

Summary Points

- Deaths secondary to guns in the United States are largely intentional and relate to the male population. The majority of firearm-related deaths in the United States, essentially two thirds, are homicides. The rate of suicide is also increasing. Minorities have a disproportionate representation among victims of gun violence. Unfortunately, health care providers frequently have limited understanding of ballistics, bullets, and guns in part due to limitations of outside information sources.
- Ballistics is the science of bodies in flight. This discipline includes physical triggers and the phases of movement of the bullet or other projectile. Based on the location of the projectile, ballistics are divided into interior (within a weapon), intermediate (leaving the barrel of the weapon), exterior (between the barrel of the weapon and a target), and terminal (penetration of a target by a projectile).
- General wound ballistics examines the development of a wound channel in tissue and describes, using physical models including velocity of the projectile and mass, transmission of energy to a target causing tissue destruction. To understand ballistic principles related to a wound, we must recognize that a projectile acts on tissue, but tissue also acts on the projectile, which may affect projectile behavior after initial tissue penetration.

- In addition to the effects of tissue on a bullet or other projectile, movement of the bullet in air before contact with tissue will also affect the pattern of impact. Characteristics of the barrel of a weapon also predict the flight of a bullet after it leaves the barrel. In general, tissues act on a bullet in a manner similar to a thickened liquid.
- A bullet may penetrate or perforate tissue depending on whether the bullet is retained in tissue or exits the body. Tissue changes are considered at a central area of tissue destruction along the path of the missile, permanent cavitation, and a surrounding area distended in a temporary manner by passage of the bullet through tissue or temporary cavitation.
- Ammunition for a gun is described as a round, shell, or cartridge. Components of ammunition include a casing; the primer, which initiates discharge of the round; propellant, which supports firing of the bullet after ignition triggered by the primer; and characteristics of the tip of the round described as a projectile or bullet that leaves the gun.
- The center of a modern bullet at the tip of a round is typically made of a soft lead, which is inexpensive, easy to work with, and readily available. The size of the entire round, including the length and shape, along with characteristics of the outer container or jacket determine the energy delivered and the tissue damage created.
- Current firearms have a variety of shapes and sizes. Handguns are represented by a variety of pistols designed to fire only a single round before reloading versus a revolver mechanism in which a rotating chamber may be loaded with several rounds using an automatic or semiautomatic mechanism where a magazine or clip automatically feeds the next round into the firing chamber before firing. A magazine or clip may contain up to 30 rounds. The rifle is categorized as a long arm, which generally delivers a higher-energy projectile over a greater distance because of rifling grooves or lands in the barrel. Projectiles enter these weapons via individual loading, clips, or magazines, allowing rapid firing of multiple rounds. In general, energy delivery with a round fired from a long-arm weapon is greater than that from a handgun.
- An exception to this generalization is the shotgun. Shotguns are a smooth bore long arm firing projectiles ranging from multiple small spherical pellets to larger spherical pellets or a single larger projectile referred to as a slug. The effective range of a shotgun is measured in yards and is far less than that of handguns or other long arms. At short range, the delivery of multiple pellets from a shotgun may cause significant tissue damage. In general, this long arm is used for hunting birds or small animals while firing a cartridge containing multiple small pellets.
- Within tissue, the length and character of a bullet track are variable. Bullet tracks are influenced by the energy of the bullet or pellets and the construction of these projectiles. In general, the liver, spleen, and brain have minimal tissue elasticity and are most severely injured by a bullet strike. Fluid-filled organs such as the bladder, heart, and great vessels may burst when struck by a projectile. Bone will fracture with secondary fragments due to a bullet strike, causing additional tissue injury. Finally, skin and lung have the least density, are elastic, and tend to be less injured in comparison with other organs listed.

Acknowledgments

The author acknowledges Ms Sherry Willett for expert preparation of this series for *Air Medical Journal*. The literature review provided by Ms Jennifer Feeken and Ms Amy Studer is also gratefully noted.

David J. Dries, MSE, MD, is a senior fellow at HealthPartners Institute, a professor of surgery and the John F. Perry, Jr, chair of trauma surgery at the University of Minnesota in St Paul, MN, and can be reached at david.j.dries@healthpartners.com.