WHEN THE BULLET HITS THE BONE: PATTERNS IN GUNSHOT TRAUMA TO THE INFRACRANIAL SKELETON

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WHEN THE BULLET HITS THE BONE: PATTERNS IN GUNSHOT TRAUMA TO THE INFRACRANIAL SKELETON

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CHAPTER 1

INTRODUCTION

"The weapon used most often with homicidal intent in modern American urban society is a firearm (Adelson 1974:188)." During Adelson's time, the number of violent crimes committed with a firearm exceeded the total deaths by all other modalities combined. Thirty years later, the FBI reported that gunshot trauma was still the leading cause of death. Over 70% of the recorded 14,121 homicides in the United States involved a firearm, with the majority involving handguns (FBI 2004).

Because of the widespread use of firearms, it is important for forensic anthropologists to be aware of the characteristics of guns and ammunition and the trauma they may cause to the human body. While research has allowed anthropologists to understand the mechanisms of wound ballistics, the variation in trauma is not fully understood. A wide variety of injuries result from these weapons that produce specific patterns of trauma. It is one of the tasks of the forensic anthropologist to identify and interpret trauma caused by different firearms and ammunition.

Ammunition

It is crucial to understand that it is not the gun that directly inflicts injury, but rather the projectile that creates bodily trauma. Firearms only facilitate the firing of the ammunition, the actual mechanism of trauma.

A single piece of ammunition includes multiple components necessary for proper operation (Fig. 1). The outer case encloses the primer, propellant, and projectile, or bullet in what is referred to as a cartridge. While the overall organization of cartridge ammunition has remained virtually unchanged for the past 900 years, each component varies from firearm to firearm (DiMaio 1999).

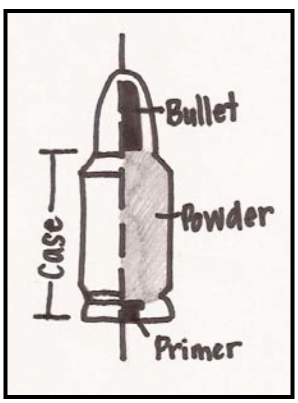

Figure 1. Cartridge anatomy (drawn by Chapman)

Once the cartridge is loaded into the weapon, it is ready to be fired. The firing process begins when the trigger is pulled. The firing pin strikes the base of the cartridge at the primer, causing an explosion. One major difference in modern ammunition is the location of the primer; located either so that the firing pin strikes at the center or on the rim of the bullet. Ammunition and firearms are classified as either 'centerfire' or 'rimfire' depending on where the firing pin strikes and will not fire properly if loaded with the opposite.

Once the primer activates, a spark produces to ignite the propellant. Finally, the bullet ejects from the cartridge and firearm. Bullet morphology has changed drastically from their early development. Before firearms were designed to shoot long, accurate distances, cartridges contained sphere-shaped bullets made of lead. Modern bullets are no longer made entirely of lead, but are coated or "jacketed" with a variety of metals. There are four general configurations of lead bullets: roundnose, wadcutter, semi-wadcutter, and hollow-point (DiMaio 1999). Roundnose bullets are the most common types of ammunition used in handguns and rifles. Wadcutters and semi-wadcutters are used in target practice, and are designed to cleanly perforate paper targets. Alternatively, hollow-points are designed to expand on impact, creating severe and broad damage to the impacted target.

Lead bullets are sometimes covered with a thin 'jacket' made of copper, zinc, steel, nickel, or aluminum (DiMaio 1999). Lead bullets are also distinguished by their jacketing as either fully metal- or partially metal-jacketed case (Fig. 2). Bullets are categorized as ball, armor piercing, tracer, or incendiary ammunition. Ball ammunition is the most common, and is composed of a simple lead bullet with a full metal-jacketed case. Armor piercing, tracer, and incendiary bullets each have different quantities of either lead or steel cores and variations of jacketing.

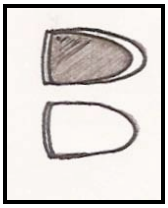

Figure 2. Jacketed bullet, cross-section and outer views (drawn by Chapman)

The United States military is a large consumer of full metal-jacketed ammunition, for it generally causes less extensive trauma upon entrance and exit (DiMaio 1983). This roundnosed bullet is more likely to produce 'through-and-through' wounds that have the potential to wound multiple individuals (Klatt et al. 1989). Modern hunters, on the other hand, generally prefer partially metal-jacketed or hollow-point ammunition in centerfire rifles. The metal jacketing coats the core of the cartridge, decreasing the likelihood of melting the lead bullet, while the hollow-point tip enables quick expansion upon impact and fragmentation within the body (Fig. 3). When fired, a hollow-point ammunition 'mushrooms' inside the body, increasing the severity of sustained wounds while decreasing the likelihood of an exit.

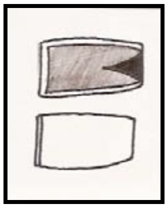

Figure 3. Hollow-point bullet, cross-section and outer views (drawn by Chapman)

Personal Firearms

Small, personal firearms are divided into five descriptive categories: handguns, rifles, submachine guns, machine guns, and shotguns (DiMaio 1999). Their differences derive from the types of ammunition they fire, the way the ammunition is fired, and the way they reload.

Handguns

Single-shot pistols and derringers are loaded manually each time the weapon is fired, either with one or multiple shots, respectively. Alternatively, revolvers contain several chambers for each shot. The cylinder of these guns rotates mechanically each time the barrel is cocked and fired, in order to access the chambers containing the shot. A revolver usually fires six shots or ‘rounds.’

Automatic pistols also load each time the trigger is pulled, but are called ‘automatics’ because of their reloading mechanisms. The forces generated by a previously fired cartridge extracts and ejects the empty case, loads a new cartridge, and returns the gun to the firing position. In most cases, these weapons’ cartridges are stored in a removable magazine in the grip of the pistol, referred to as a clip.

The velocity of the bullet fired from the muzzles of handguns and pistols is around one to two thousand feet per second (Bono and Heary 2003). Firearm experts conventionally label handguns as ‘low-energy’ or ‘low-velocity,’ based on the weapon itself and the kind of ammunition it fires.

Rifles

Rifles are much larger than handguns and are designed to be fired from the shoulder. The term ‘rifle’ comes from the spiral grooves cut into the barrel of the weapon. This rifling spins the bullet, improving its accuracy and range, while retaining its maximum muzzle velocity. While the length of the barrel is unimportant in the classification of the firearm as a rifle, U.S. Federal Law requires all rifles to have a minimum barrel length of sixteen inches (DiMaio 1999). Rifle cartridges are loaded either manually or automatically.

Traditionally, military and police forces have been the sole consumers of automatic weapons. While uncommon, semi-automatic rifles can be altered to perform the duties of a fully automatic weapon, but are extremely difficult to control and are rarely accurate (DiMaio 1999).

Assault rifles are also utilized by militaries around the world. These rifles are fully automatic and fire twenty or more rounds from detachable magazines. In general, they are easy to fire and have immense power.

Submachine and machine guns are similar to assault rifles except that they fire pistol or rifle cartridges, respectively.

In general, rifles with muzzle velocities greater than three thousand feet per second are considered ‘high-energy’ or ‘high-velocity’ weapons (Bono and Heary 2003).

CHAPTER 2

BALLISTICS

A specific, physical process occurs when any gun is fired. This process can be outlined through a set of scientific reactions and equations. Once the trigger of a firearm is pulled, the pressure of the propellant's gasses is released forward, through the barrel of the gun, and out of its muzzle. The analysis of this progression is termed *interior ballistics* (Sellier and Kneubuehl 1994).

Exterior ballistics is the time that the bullet spends outside of the gun, before it hits the target. Analysis is made of the projectile's trajectory, its drag through the air, and its probability of flight alteration in relation to other variables (Sellier and Kneubuehl 1994).

The final step in a bullet's progression is that of *terminal ballistics*, the examination of the changes that occur when a target is struck by a projectile and the counter-effects upon the impacted bullet (Sellier and Kneubuehl 1994).

When the target is a human body, *wound ballistics* describe the effects of bullets on wounded individuals. These factors are dependent on the type of weapon and ammunition fired (Sellier and Kneubuehl 1994).

Wound ballistics

Upon impact with the human body, projectiles will cause major damage to surrounding organs, bones, and other living tissues. Various kinds of wounds will occur depending on the combined action of the bullet's speed, size, shape, and motion in flight, as well as the density, cohesion, and character of the tissues struck (Adelson 1974). A bullet's ability to wound varies in reference to its loss of kinetic energy upon impact (DiMaio 1999). The bullet's principal kinetic energy is equal to half of its mass multiplied by its velocity squared: $KE = (1/2)\, m \bullet v^2$. In relation to ballistics trauma, "one bullet traveling twice the speed of a second bullet of equal weight and similar shape possesses four times as much wounding power" (Adelson 1974:193).

The loss of kinetic energy that occurs after a projectile penetrates the human body is directly related to its potential for wounding (DiMaio 1999). This process depends on three factors.

The first factor is related to the features of original kinetic energy of the bullet (DiMaio 1999). The velocity of the traveling bullet is twice as important in determining kinetic energy, as is its mass. Bullets travel at a wide range of speeds, depending on the propelling firearm, and the caliber, construction, configuration of the bullet (DiMaio 1999).

Therefore, the type of weapon, its natural velocity, and the fired ammunition will affect the bullet's kinetic energy at the point of impact.

Another factor in kinetic energy loss is the angle of yaw at penetration. Once a bullet is fired, it is subject to the physical laws of gravity, force, and movement. It is probable that the bullet will begin to yaw, or tumble over its long axis during flight. In this case, the bullet's path is altered, causing the larger point of impact. Other factors that can affect yaw include rifling, altered or modified weapons, distance, and ambient climate (DiMaio 1999).

The final characteristic in determining loss of kinetic energy is the type of tissue struck by the projectile. The density, strength, elasticity, and size of the wounded area are directly related to the amount of energy lost, further affecting the length of penetration. The harder the tissue struck the greater the amount of resistance, which in turn will produce more substantial trauma (DiMaio 1999). This fact applies to any portion of the body, from the slightest flap of skin to the densest piece of bone.

After accounting for each of these factors, wound formation is still affected by the amount of penetration into the body. If a bullet enters the body but does not exit, all of the kinetic energy is lost within the body. If that same bullet perforates the body completely, some energy would have to remain in order for the bullet to exit. The entrance wound in the second case would be less severe than in the first because less energy was lost on impact (DiMaio 1999).

Trauma

No matter the type of firearm or ammunition fired, bullets passing through a human body can cause a great deal of trauma. Superficially, this trauma is a result of the destruction of tissues in the immediate path of the bullet. At the same time, surrounding tissues separate from the bullet, creating a temporary cavity considerably larger than the diameter of the bullet (DiMaio 1999). Shortly thereafter, this temporary cavity collapses and a permanent wound track remains. Fackler (1986:1451) determined that the mechanisms of trauma were a result of the "crush and stretch" of tissues from the penetrating projectile (Fig. 4).

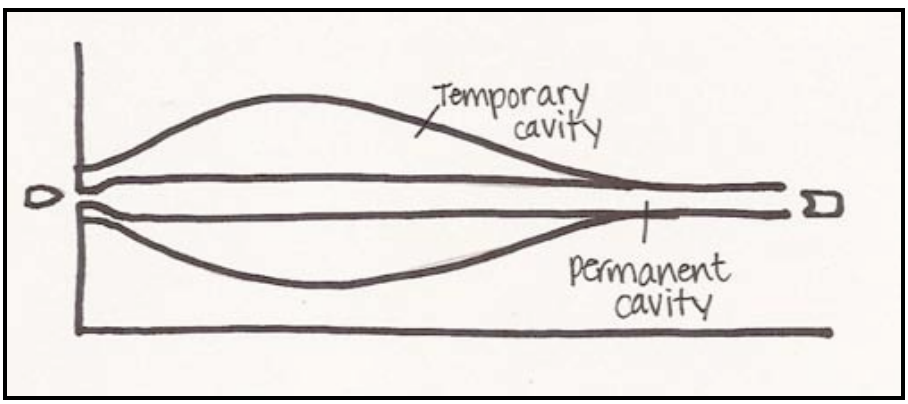

Figure 4. Temporary and permanent cavities created by a full metal-jacketed bullet (referenced from Fackler 1996:196)

In general, high-velocity firearms create the greatest amount of trauma by generating the largest temporary and permanent cavities (Huelke et al. 1968). However, "bullet energy is not the sole determinant of the extent of injury" (Bono and Heary 2003:231). The size and shape of temporary and permanent cavities depend on the amount of kinetic energy lost, the type of bullet fired, and the density and elasticity of the injured tissues. The maximum diameter of the temporary cavity is many times the diameter of the bullet (DiMaio 1999). Its creation and subsequent collapse plays a significant role in the extent to which an individual is wounded. The temporary cavity follows the path of least resistance, separating tissues and muscles, and displacing organs (Fackler 1996).

This fact is especially true for roundnose bullets, which are built specifically to perforate their targets. The temporary and permanent cavities of roundnose bullet wounds follow a straight path, from the entrance through to the exit.

The damage caused by roundnose bullets is usually less than wounds produced by hollow-point bullets (Fackler 1996). Where roundnose bullets move directly through the body, hollow-point bullets expand upon impact, causing an injury 'focal point.' When a hollow-point bullet hits its target, the temporary cavity is similar to an explosion (Fig. 5). Once the bullet has struck the target, it is extremely vulnerable to fragmentation, causing as much trauma as the original wound (Klatt et al. 1989). The permanent cavities of hollow-point bullet wounds are especially jagged and wide, and rarely display exit wounds (Fackler 1986).

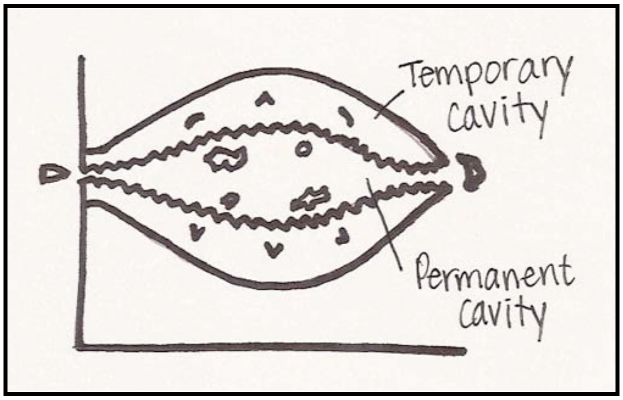

Figure 5. Temporary and permanent cavities created by a hollow-point bullet (referenced from Fackler 1996:196)

CHAPTER 3

FORENSIC ANTHROPOLOGY

Death is often a result of trauma to the vital organs throughout the body. The skeletal system that protects these organs may also display permanent defects from traumatic activities. Upon examination of the skeleton of a deceased individual, forensic anthropologists are likely to be capable of providing information about traumatic events surrounding death.

Assessment of gunshot wounds

Gross examination of human remains consists of locating and describing trauma. This is true for medical doctors, forensic pathologists, and forensic anthropologists. Particular to gunshot victims, initial analyses are made via location of the wound, and identifying factors such as type of weapon, entry and exit wounds, number of wounds, distance of the weapon to the wound, and the time of wounding in relation to death. Each form of identification is based on the characteristics of the wound itself and the state of the remains.

In homicide cases involving firearms determining the caliber of the weapon is a crucial step in the investigation. Many researchers have attempted to identify specific weapons and ammunition in relation to the wounds they create (e.g., Berryman et al. 1995; DiMaio 1983; Klatt et al. 1989; Ragsdale and Josselson 1988). However, during the formation of temporary and permanent cavities, the “crush and stretch” is too variable to leave specific, exact replicas of the calibers creating the wound (Fackler 1986:1451). While bones are one of the densest tissues, they are still pliable and act accordingly. Bone bends inward with the traveling bullet, only to snap back outward after the projectile has moved on (Melbye 2007, personal communication). This process is extremely variable and difficult to predict. Furthermore, there is such variation within and between handguns, rifles, shotguns, and their ammunitions, making it difficult to correctly estimate caliber solely on examination of the gunshot wound (Berryman et al. 1995). Even so, with more research and examination forensic anthropologists can continue to properly identify gunshot trauma.

For forensic pathologists, identifying entrance and exit wounds is a basic process. Entrance wounds appear as punched or folded in. Often, wound surfaces will show an abrasion ring, identified by reddish-brown abraded skin. This is not due to burning, but rather from the abrasion or tearing of the flesh (DiMaio 1999). The appearance of the abrasion ring is dependent on location of wound, distance of weapon from target, and type of weapon fired.

Exit wounds are generally irregular in shape and greater in size than associated entrance wounds (DiMaio 1999). This is due to three factors affecting loss of kinetic energy; the original velocity and mass of the bullet, the amount of yaw at penetration, and the location and type of tissue struck. Each of these factors plays a role in determining the size, shape, and location of the entrance wound. Victims of gunshot trauma may not always display both entrance and exit wounds because the bullet's kinetic energy may not have been significant enough to completely perforate the body (DiMaio 1999).

It is sometimes possible to determine the distance of a weapon in reference to the entrance wound (DiMaio 1999). Forensic pathologists examine markings on the skin and relate them to particular distances and locations. For example, contact wounds might display gunshot residue, soot, or other deposits from the gasses of the barrel (DiMaio 1999). From a greater distance, weapons might leave stippling or powder tattoos. These dark markings are abrasions left on the skin or bone from powder grains that emerge from the muzzle as the bullet is fired. Stippling spreads in a regular pattern in relation to distance from which the weapon was fired (DiMaio 1999).

While forensic pathologists generally describe and analyze gunshot trauma in recently deceased individuals, forensic anthropologists often examine this trauma in skeletonized remains. Patterns of gunshot trauma described in the previous chapter are also applicable to the skeleton. The bones of the body are living tissue and act accordingly. However, the density of bone is greater than soft tissues and organs, so it reacts to impact differently. Wound ballistics in relation to the skeletal system is of particular interest to the forensic anthropologist.

Fractures

To fully understand gunshot wounds in the skeleton, we must revisit wound ballistics. At this point, we are familiar with the fact that a bullet's ability to wound is directly related to its kinetic energy. "If a projectile hits a bone directly, with the necessary velocity, the bone breaks" (Sellier and Kneubuehl 1994:294). While soft tissues and organs react to impact by "crushing and stretching," bone displays similar trauma in the form of a fracture (Amato 1989). Bone fractures can be caused by exterior impact at excessive speeds, impact to a vulnerable point, or impact directed in an abnormal direction (Byers 2002). Specifically, projectiles subject bone to dynamic, sudden, and high-speed stress, at single point in a bending direction. When each of these forces combines in ballistics trauma, bone will fail and fracture.

In order for a projectile to cause damage, the exerted force must be stronger than that of the bone. DiMaio (1999) noted that bullet penetration did not occur until a minimum velocity between 200 and 560 feet per second was reached. Studies by the United States Army Medical

Department also concluded that a "minimal velocity of approximately 200 feet per second was necessary to effect penetration" (Harvey et al. 1962:139). Sellier and Kneubuehl (1994) placed their "threshold velocity" around 195 feet per second, depending on the size and weight of the ammunition and target bone. Huelke et al. (1968) supported these thresholds as appropriate penetration levels, yet reevaluated the necessary velocity for maximum visible damage at around 700 feet per second.

Once the minimum velocity of bone is reached and penetration occurs, the wounding process continues. A temporary cavity stretches bony tissues, resulting in a permanent cavity of almost equal size (Huelke et al. 1968). These wounds are displayed as various fractures, depending entirely on the three factors that influence a projectile's loss of kinetic energy; bullet construction and velocity, amount and direction of yaw, and composition of affected tissues.

Fracture classification for this study was based on Adams' Outline of Fractures: Eighth Edition (1983). This volume classifies fractures based on their etiology into three groups: fractures caused by sudden force, those caused by stress or fatigue, and pathological fractures (Adams 1983). Ballistics trauma occurs at sudden and high speeds, so this study will mainly focus on the fractures related to the first group: sudden force.

A subdivision can be made between fractures caused by either direct or indirect trauma (Adams 1983). For example, if a heavy weight is dropped directly on your foot, the structure of your metatarsal bones will fail and fracture. Alternatively, if you tripped and fell onto outstretched hands, portions of your radius and ulna will be indirectly affected and might fracture.

Long bone fractures can occur at the proximal end, the distal end, or along the shaft, which is further described as the proximal one third, distal one third, or mid shaft. Fracture terminology is based on "the shape or pattern of the fracture surface," (Adams 19983:5) which can be labeled as a transverse fracture, oblique fracture, spiral fracture, comminuted fracture, compression and compacted fracture, or greenstick fracture (Adams 1983). A transverse fracture appears at a right angle to the bone's long axis (Fig. 6a). An oblique fracture is diagonal to the bone's long axis (Fig. 6b). A spiral fracture occurs when the bone has been twisted and appears diagonal to the long axis (Fig. 6c). A comminuted fracture creates multiple fragments of fractured bone (Fig. 6d). A compacted fracture occurs when fractured bone is forced into other sections of bone. A compression fracture occurs only in the vertebrae, when weakened sections of the vertebral body become compacted (Fig. 6e). A greenstick fracture occurs mainly in children and appears as an incomplete fracture that does not break through the entire bone (Fig. 6f).

Fractures labeled as comminuted are severely fragmented and can be further delineated based on the number of remaining bony fragments. Each type of fracture is subject to bone loss, where less than fifty percent is lost, greater than fifty percent is lost, or a segmental portion of the shaft is missing.

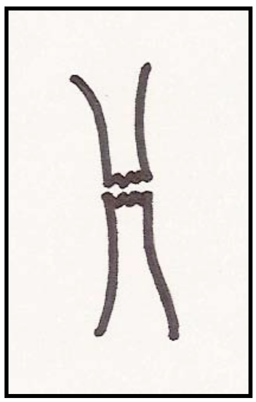

Figure 6a. Transverse fracture (referenced from Gustilo 1991:3)

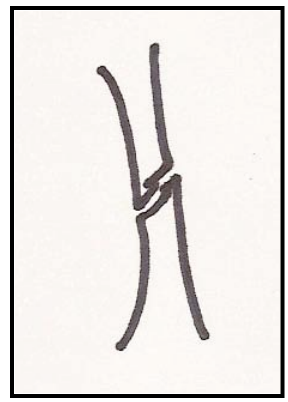

Figure 6b. Oblique fracture (referenced from Gustilo 1991:3)

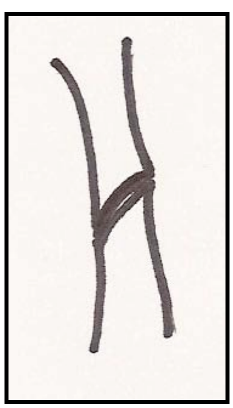

Figure 6c. Spiral fracture (referenced from Gustilo 1991:3)

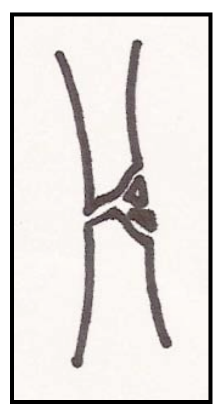

Figure 6d. Comminuted fracture (referenced from Gustilo 1991:3)

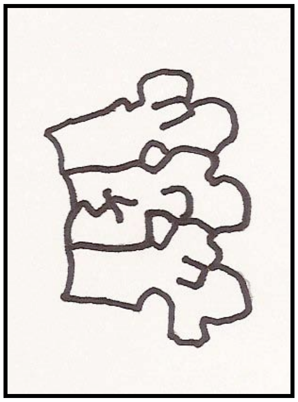

Figure 6e. Compression fracture (drawn by Chapman)

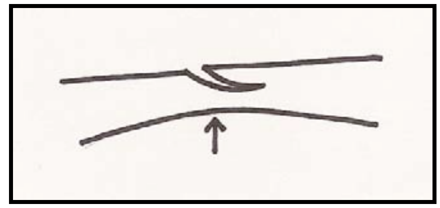

Figure 6f. Greenstick fracture (drawn by Chapman)

Bone fractures of the proximal and distal ends vary greatly from those found at the shaft (Huelke and Darling 1964). In general, entrance wounds at the ends of the shaft of the bone, or metaphyses, are sharp and oval-shaped, with few radiating fractures. Huelke (1964:463) described the circular defect related to bullet entry as appearing similar to a “drill hole” (Fig. 7). Upon exit, the wound is greater in size and more irregular shape, and produces comminuted fractures. At the shaft, gunshot impact generally fractures bone into two or more separate pieces (Huelke and Darling 1964). Upon reconstruction, it is possible to determine the point of impact, which is surrounded by a butterfly-shape of radiating fractures (Fig. 8). Butterfly-shaped fractures may occur in blunt force trauma or gunshot wounds, “when the external force produces angulation fractures” (Ubelaker and Adams 1995:509). In the case of gunshot trauma, the entrance of the bullet forces the bone to bend, creating enough stress to produce multiple radiating fractures (Ubelaker and Adams 1995).

Figure 7. Entrance wound at the metaphysis (Huelke and Darling 1964:463)

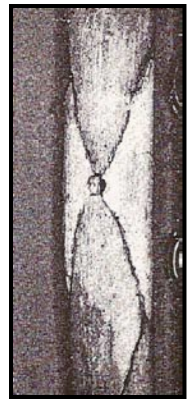

Figure 8. Exit wound with butterfly-shaped radiating fractures (Huelke and Darling 1964:466)

Radiating fractures occur secondarily after the impact of a projectile on bone. Bone is a solid structure that can be compared to a pane of glass. Once a moving projectile strikes the pane, the dissipation if energy is displayed as cracks in the glass, centered around the point of impact. Likewise, as a bullet hits its target, all or most of the kinetic energy is released into the bone. The bone must be strong enough to stop the bullet or its structure will fail and fracture. Like the pane of glass, radiating bone fractures occur as the point of impact loses kinetic energy throughout the shaft.

The difference in fracture patterns between the metaphyses and the proximal and distal ends occurs due to the composition of penetrated bone. The distal and proximal ends are composed of cancellous tissues that can act to decrease the amount of kinetic energy lost upon impact. The spongy bone dissipates the pressure, which results in less trauma (Huelke and Darling 1964). On the other hand, the bone shaft experiences greater damage because of its hard cortical structure. This strong, bony covering has a greater resistance to penetration and can withstand a large amount of pressure upon impact, but when a gunshot wound forms its temporary cavity, the shaft's structure fails easily and fractures (Huelke and Darling 1964).

In a clinical experiment by Smith and Wheatley (1984), both wet and dry bone studies demonstrated the occurrence of circular defects related to bullet entry in metaphyses and butterfly-shape of radiating fractures, with varying degrees of fragmentation in shafts. Fragmentation of the shaft depended on "the amount of pressure generated within the bone" (Smith and Wheatley 1984:971). In other words, fragmentation increased in relation to the amount of energy lost upon impact and the composition of the bone struck.

Cranial gunshot wounds

Gunshot wounds to the skull are of particular interest to the forensic anthropologist. The various fracture patterns are unique because of the squama's composition and morphology. In particular, beveling is one of the most obvious responses of cranial bone to ballistics trauma, and it is usually consistent with the path of the bullet. Once again, this may be described by visualizing a pane of glass. If a BB is shot through the window of a house, the hole on the outside will be clean and small with sharp edges. On the inside, the hole will be beveled: larger, irregular in shape with jagged edges (Fig. 9). The presentation of this pattern of beveling can lead to the identification of entrance and exit wounds, direction and angle of wound, and perimortem body position. One can generally assume that a "circular, internally beveled defect… is consistent with a bullet that strikes the vault perpendicularly, and a circular, externally beveled defect is consistent with an exit (Berryman and Gunther 2000:483)."

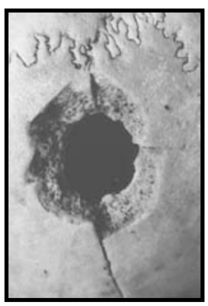

Figure 9. Typical exit beveling (http://www.soton.ac.uk/~jb3/bullet/gsw.html)

However, there have been cases of atypical beveling of gunshot wounds to the skull. An atypical wound can occur when the weapon is in direct contact with the skull. In this case, the forces of the gasses and the dissipating energy inside of the skull can become so great that the bone blows back towards the shooter (Melbye 2007, personal communication). This unique entrance wound takes on the appearance of an exit, with a large size, irregular beveling, and jagged edges.

Another atypical bevel defect is called the keyhole fracture (Fig. 10). Keyhole fractures exhibit “characteristics of both gunshot entrance and exit wound trauma (Berryman and Gunther 2000:483).” Keyholes are very rare but can occur when the bullet grazes the skull at an angle, when the bullet is yawing, or if there is not enough force for the bullet to penetrate the skull (Berryman et al. 1995; Quatrehomme and Iscan 1999). Physically, the wound takes on the appearance of both entrance and exit wounds, with a circular defect related to the entrance of the bullet, and a irregular triangular exit defect beveling in the direction of the path of the bullet (DiMaio 1999; Quatrehomme and Iscan 1999). In the example of Figure 10, the bullet would have entered the skull from the right, identified by the circular defect and resulting radiating fractures and beveling.

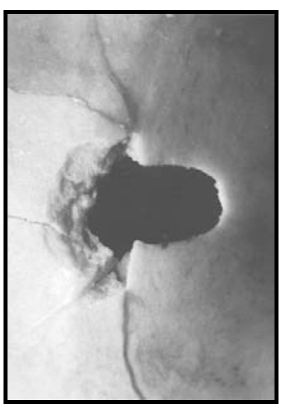

Figure 10. Keyhole fracture of the skull (http://www.soton.ac.uk/~jb3/bullet/gsw.html)

Berryman and Gunther (2000) presented a case study in which a tangential gunshot wound to the humerus displayed the characteristics of keyhole fracturing (Fig. 11). The victim was hit with two bullets, one of which impacted the left humerus in such a way that created an atypical entrance wound. In this rare case, the secondary radiating fractures from the immediate point of impact formed a hinge on the surface of the bone. The wedge-shaped piece of bone became dislodged as the bullet moved beneath it, leaving a keyhole defect in the humerus. Figure 12 displays the characteristics of the fracture during each stage of its production, from the immediate entrance of the bullet, to the production of the radiating fractures, hinge, and subsequent keyhole defect. Again, while rare, the appearance and identification of keyhole fractures in long bones may be "useful in determining bullet direction and body position" (486).

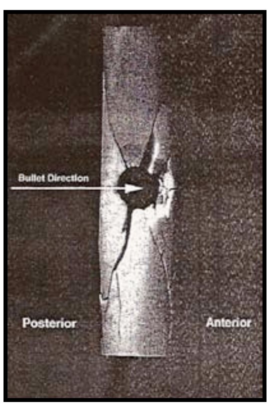

Figure 11. Keyhole fracture (Berryman and Gunther 2000:483)

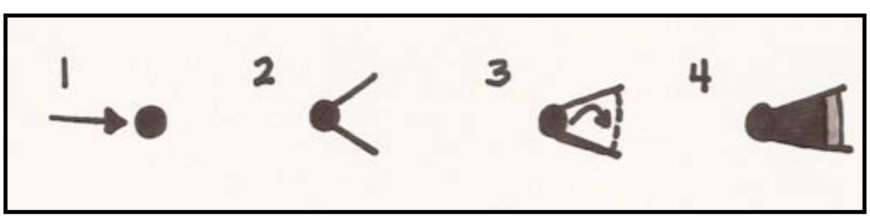

Figure 12. Stages of the keyhole fracture (referenced from Berryman and Gunther 2000:486)

Consequential damage

Secondary fractures occur almost immediately after a projectile impacts the skull. These fractures appear so quickly because of the release of energy from both the bullet and from the pressures inside of the cranial vault. Radial fractures form first, at the point of impact (Fig. 13a). Then, "concentric heaving fractures appear as a series of arcs or generations of circular fractures centered around the point of impact and connect the radial fracture lines" (Smith et al. 1987:1417) (Fig. 13b). Secondary fractures always occur in the same order and arrest at previously occurring lines. Exit wounds also may display radiating and concentric fractures (Fig. 13c). In cases of multiple gunshot wounds to the head, understanding of the timing and phases of fracture patterns is crucial to determining the sequence of wounds.

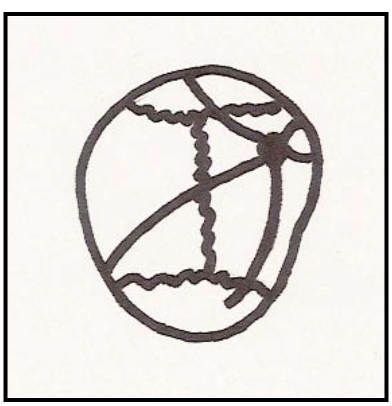

Figure 13a. Radiating fractures in the skull (referenced from Smith et al. 1987:1417)

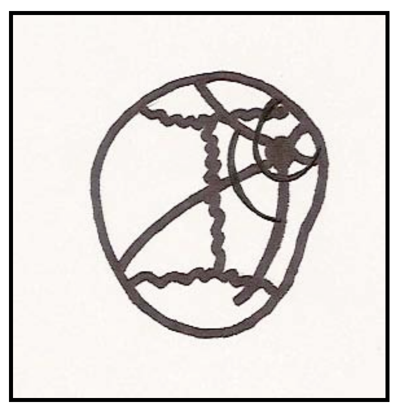

Figure 13b. Concentric fractures (referenced from Smith et al. 1987:1417)

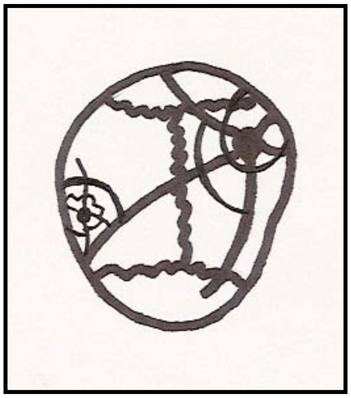

Figure 13c. Radiating fractures associated with exit wounds (referenced from Smith et al. 1987:1417)

Thus far, the discussion has centered on the first fracture classification subdivision: direct gunshot trauma. However, it is possible for bones to break indirectly or when bullets pass within close proximity (Adams 1983). Smith and Wheatley (1984) examined cadavers who experienced spiral fractures of the femoral shaft, remote from the wounding site. The bullet wounds displayed the butterfly-shaped radiating fractures at the point of impact. Other changes not related to the point of impact were also noted, and also caused by indirect impact.

Wound ballistics describes the process in which temporary cavities are created when a projectile passes through its target. Forces directly related to the projectile's loss of kinetic energy temporarily displace tissues and organs. As the bullet moves forward and tissues move away, a "shock wave" travels through the point of impact (Sellier and Kneubuehl 1994:294). "The larger the surface area presented to the target by the on-rushing projectile, the greater the magnitude of the 'shock wave' produced" (Harger and Huelke 1970:492). This impact creates a simple, spiral fracture in the bone rather than the comminuted fractures that are a result of temporary and permanent cavity formation (Harvey et al. 1962).

Secondary missiles displaced from the temporary cavity can also cause a great deal of trauma (Harvey et al. 1962). Minute fragments from impacted bone may affect a wider diameter than the original gunshot wound, causing further trauma to other portions of the body, "magnifying the damage far beyond the simple drilling effect of the projectile itself" (Harger and Huelke 1970:492). These damaging projectiles have been readily observed in case studies under radiographs, traveling in the same forward movement as the direction of the bullet (Amato 1989). Harger and Huelke (1970:492) described this as the "cavitation effect," a tremendous amount of damage from gunshot wounds that occurs when impact velocities reached around 800 feet per second. Most commonly, they come from bone and deformed pieces of bullet jacketing or casing.

Ragsdale and Josselson's (1988) study quantified the amount of displaced material that resulted from gunshot wounds to the long bones of the leg. They surrounded multiple femora and tibii in gelatin, shot them with different firearms, and observed the quantity and quality of fragmentation. They found that secondary fragments, such as bits of bullet, jacketing, and bone shards had an equal possibility of lethality as the original gunshot wound did. In other case studies, the damage even extended to tertiary fracture zones, depending on the velocity level of the firearm (Robens and Kusswetter 1982). This trauma is displayed on radiographs as an explosion from the point of impact to proximal regions. In dry bone it is more difficult to determine, but can present as jagged, blown out fracture edges with a large area of bone loss. Each of these researchers was able to distinguish the damage created by secondary fragments from the damage created by original gunshot wounds (Fig. 14). Furthermore, the amount of fragments and fragmentation damage was significantly higher in bones impacted by hollow-point bullets than those shot with fully metal-jacketed bullets (Ragsdale and Josselson 1988).

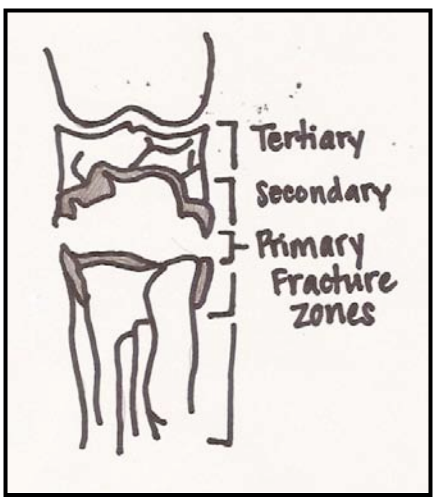

Figure 14. Fracture zones (referenced from Robens and Kusswetter 1982:227)

CHAPTER 4

GUNSHOT IDENTIFICATION

In modern cases, forensic anthropologists may play a crucial role in helping law enforcement officers to identify human remains. One of elements of the forensic anthropologist's responsibilities is in identifying fractures induced by specific forces, such as gunshot trauma.

The processes involved in gunshot wound formation are directly related to the wound's physical appearance. There are multiple variables that affect gunshot wound formation, and a wide array of data surrounds wounds to the skull because the orientation and composition of the squama allows for distinctive and predictable trauma (Berryman et al. 1995; Berryman and Gunther 2000; DiMaio 1999; Smith et al. 1987).

This research project will examine gunshot wounds to the infracranium. Particular patterns of trauma will be identified, analyzed, and compared to current knowledge about primary and secondary fractures. This study will revisit wound ballistics and kinetic energy, and relate them to the physical characteristics of gunshot trauma in the infracranium. These variables will be tested using the ammunition of different firearms, weights, calibers, jacketing, and velocities. After examination and comparison, it may be possible to predict (to some extent) the amount of trauma incurred by specific firearms and ammunition.

Materials and Methods

The goal of this research study was to determine the effects of gunshot trauma on the *infracranial* skeleton, or the bones below the skull. However, human cadavers could not be acquired for this study and the carrion of feral hogs (*Sus scrofa)* were used as analogues. Hogs are commonly used as substitutes for human cadavers in forensic anthropological research because of their similar anatomical structure, fat content, and decomposition rate. "While the recommended size for study hogs is approximately 23 kilograms, variation is size does not influence taxa present" (Davis and Goff 200:837). Keeping this in mind, the actual bones studied for this research were *postcranial*, or behind the skull (Fig. 15). The structure of a hog skeleton is often used in place of human cadavers because of their similarities in anatomy, fat content, and decomposition rates. The focus of this study will remain on the *infracranium* and is referred to as such from this point forward.

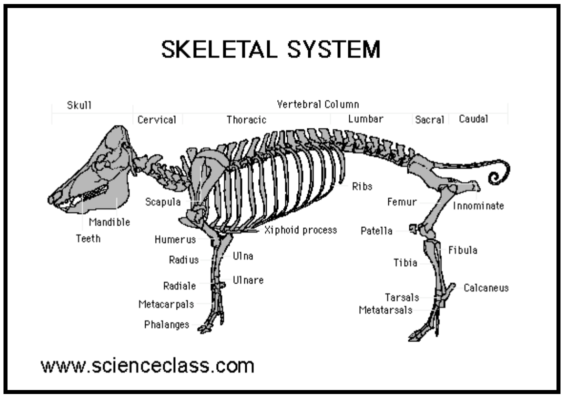

Figure 15. ***Sus scrofa*** **skeletal system (http://www.k12sciencestore.com/support/dissectionworks/pictures/pig/label/skeletal_system_1.gif)**

The corpses of five feral hogs were purchased from a local farmer, chosen based on uniformity of height and weight. Maximum height measurements were taken from the rear hoof to the top of the haunches. Maximum lengths were taken from the back of the neck to the haunches. The head was not included in the measurements because it was not a focus of the study. Each subject was weighed using a hunter's basic field-dressing scale and was an average of 120 centimeters in length, 60 centimeters in height, and weighed approximately thirty kilograms. The subjects were stored in a freezer at the Early ranch for three months until research could begin. When the time came, the subjects were thoroughly thawed and labeled, measured, and weighed. Each subject was randomly assigned to a firearm provided by the Comal County Sheriff's Office (Table 1). Individually, the subjects were hoisted by their hind limbs and secured into a homemade gambrel and stand, so that the head and forelimbs rested on the base and supported the majority of the body weight. The subjects were positioned with their flanks towards the shooter, to provide the largest and clearest target of the infracranium (Fig. 16). The shooter, a ballistics expert from the Comal County Sheriff's Office, fired four shots at each subject, aiming once at the forelimbs, once at the hind limbs, and twice at the broad side of the abdomen. If the target was not stuck on the first attempt, the shooter spent another round. The distance of the shooter from the subjects was determined by the type of firearms and in accordance with the definition of a distance gunshot wound by DiMaio (1999). The rifles were fired from a distance of ten meters and the pistols were fired from three meters.

Table 1. Subjects' Information

Subject	Length	Height	Weight	Firearm	Cartridge	Velocity m/s	Velocity ft/s	Kinetic energy
1	124.46 cm	66.04 cm	30.84 kg	AK - 47	7.62 x 39 mm, 123-grain HP	701.04 m/s	2300 ft/s	1610 J
2	114.3 cm	60.96 cm	23.13 kg	.308 Winchester	7.62 x 51 mm, 168-grain HP	792.48 m/s	2600 ft/s	2180 J
3	127 cm	60.96 cm	28.12 kg	9 mm	115-grain HP	381 m/s	1250 ft/s	399 J
4	119.38 cm	50.8 cm	26.31 kg	9 mm	147-grain HP	297.18 m/s	975 ft/s	310 J
5	129.54 cm	71.12 cm	30.84 kg	9 mm	124-grain FMJ	341.376 m/s	1120 ft/s	345 J

HP = Hollow-point **FMJ = Full metal-jacketed**
m/s = Meters per second **ft/s = Feet per second**
J = Joules of energy

Figure 16. Gambrel and stand (photograph by Chapman)

Subject One

Subject One was shot with an AK-47 assault rifle at a distance of ten meters (Fig. 17). The rifle was loaded with 7.62 x 39 millimeter, 123-grain hollow-point cartridges (Fig. 18). When fired, these bullets traveled at about 2,300 feet per second (701.04 meters per second) and hit the target with about 1,610 joules of energy.

Figure 17. AK-47 rifle (photograph by Chapman)

Figure 18. 7.62 x 39 mm, 123-grain hollow-point cartridges (photograph by Chapman)

Subject Two

Subject Two was shot with a .308 Winchester rifle at a distance of ten meters (Fig. 19). The rifle was loaded with 7.62 x 51 millimeter, 168-grain hollow-point cartridges (Fig. 20). When fired, these bullets traveled at about 2,600 feet per second (792.48 meters per second) and hit the target with about 2,180 joules of energy.

Figure 19. .308 Winchester rifle (photograph by Chapman)

Figure 20. 7.62 x 51 mm, 168-grain hollow-point cartridge (photograph by Chapman)

Subject Three

Subject Three was shot with a nine-millimeter pistol at a distance of three meters (Fig. 21). The pistol was loaded with 115-grain jacketed hollow-point cartridges (Fig. 22). When fired, these bullets traveled at about 1,250 feet per second (381 meters per second) and hit the target with about 399 joules of energy.

Figure 21. Nine-millimeter pistol (photograph by Chapman)

Figure 22. 115-grain jacketed hollow-point cartridge (photograph by Chapman)

Subject Four

Subject Four was shot with a nine-millimeter pistol at a distance of three meters. The pistol was loaded with 147-grain bonded hollow-point cartridges (Fig. 23). When fired, these bullets traveled at about 975 feet per second (297.18 meters per second) and hit the target with about 310 joules of energy.

Figure 23. 147-grain bonded hollow-point cartridge (photograph by Chapman)

Subject Five

Subject Five was shot with a nine-millimeter pistol at a distance of three meters. The pistol was loaded with 124-grain full metal-jacketed cartridges (Fig. 24). When fired, these bullets traveled at about 1,120 feet per second (341.376 meters per second) and hit the target with about 345 joules of energy.

Figure 24. 124-grain full metal-jacketed cartridge (photograph by Chapman)

After shooting, the subjects were removed from the stand, individually bagged, and labeled. They were transported to the Bexar County Medical Examiner's Office to be radiographed.

After the radiographs, the subjects were transported back to the Texas State University-San Marcos anthropology laboratory. The next stage of this study involved processing of the bodies to remove adhering soft tissues. First, the subjects spent approximately two months decaying naturally outside, secured by chicken wire and wooden cages. After most of the soft tissue had either decayed or mummified, the subjects were individually placed in large metal drums filled with tap water and simmered for about twenty-four hours. This process removed the majority of the soft tissues and hair from the remains. Finally, the subject's bones were soaked in a fifty percent tap water and fifty percent peroxide mix for another twenty-four hours, in order to remove the remaining soft tissues.

The transportation and processing of the subjects' remains resulted in a significant amount of damage to the bones. In some cases, evidence of ballistics trauma was lost because of the complications of processing. These issues will be addressed in the conclusion chapter.

After complete processing, the subjects were reconstructed according to anatomical texts (e.g., Frandson 1965; Gilbert 1990). Each individual bone was identified, labeled, and grossly examined. If the bone displayed some form of damage, it was described, viewed under the microscope, photographed, and compared to the associated radiograph. After complete analysis, the remains of the subjects were packed into cardboard boxes for curation.

Sixty-six bones of the infracranium were of interest for this study, including 26 vertebrae, right and left scapulae, humeri, radii, ulnae, innominates, femora, tibiae, fibulae, and 24 ribs (Appendix A). When elements of the bones of interest were recovered, they were examined and reported as having no damage, gunshot-related trauma, or postmortem trauma. The term *gunshot-related trauma* was used to describe any damage that was a result of the entrance of a bullet into the body of the subject. This may have been a product of the bullet striking the bone, an effect of the production of the temporary cavity, or damage from secondary fragments of bullets and other injured bones. Any fractures suspected of being gunshot-related were examined against microscopic indicators, radiographs, and physical characteristics, such as fracture patterns and stippling. If these characteristics were clear and unmistakable, the bone was considered damaged by gunshot.

The term *postmortem trauma* was used to describe as any damage that occurred after the subjects were shot, processed, or analyzed. This damage may have been a result of the extensive transportation of the remains, processing, or examination. These fractures did not appear on radiographs because they occurred after processing. In most cases, the damage was displayed as pushed in, crumbling, or flaking fractures, with loss of cortex that appeared as bony-white colored, jagged edges. It is likely that gunshot-related trauma was underreported because of the large quantity of bones damaged postmortem.

CHAPTER 5

RESULTS

The results of the analysis of each subject are presented at the end of the text in Tables 2 – 6. Each table summarizes the skeletal elements recovered from each subject. In some cases, the complete bone was recovered, while in other cases, only a small portion or particular element survived to be analyzed. Each element was identified as undamaged, damaged from gunshot trauma, or damaged postmortem in accordance with established definitions. Any gunshot damage was described by the location, fracture classification, and cause. The following results section summarizes the overall damage to each subject, and then specifically outlines any injuries that were a result of ballistics trauma.

Subject One: AK-47 Rifle

Subject One remained complete; all sixty-six bones were recovered. Fourteen of the recovered bones (21.21%) were fractured by gunshot trauma and fifty (75.76%) were damaged postmortem (Table 2). The remaining two recovered bones (3.03%) were undamaged.

The second, third, and fourth thoracic vertebrae were fractured transversely through the body and distal one third of the spinous process. Oval-shaped fractures of compressed bone traversed the length of the remaining portions of the spinous processes (Fig. 25). The twelfth and fourteenth thoracic vertebrae displayed comminuted fractures through the bodies, transverse, and spinous processes (Fig. 26). From the first to the fifth lumbar vertebrae, every body was transversely fractured into two sections, with damaged processes. The most damage was to the second and third lumbar vertebrae: the second lumbar vertebra displayed a transverse fracture of the right transverse process and the right inferior articular facet. The third lumbar vertebra displayed transverse fractures of all of the processes, compacted fractures of the spinous process, and a comminuted fracture of the right superior articular facet.

Figure 25. Second, third, and fourth thoracic vertebrae (photograph by Chapman)

Figure 26. Fourteenth thoracic vertebra (photograph by Chapman)

The right scapula displayed a severely comminuted wound with radiating fractures and bone loss around the axillary border (Fig. 27).

Figure 27. Right scapula (photograph by Chapman)

The right and left innominates also displayed severe trauma, particularly to the left and right ilium and the left ischium. A small element (4.9 millimeters by 5.6 millimeters) of the left ilium was recovered, as a result of a severely comminuted fracture (Fig. 28). The element was fractured on all borders and missing a wedged-shaped portion of the inferior side. The right ilium was fractured longitudinally through the ala (Fig. 29). The left ischium displayed a spiral fracture through the intersection of the inferior rami of the pubis and ischium (Fig. 30). The right and left public bones were damaged greatly and could not be completely analyzed.

Figure 28. Left ilium (photograph by Chapman)

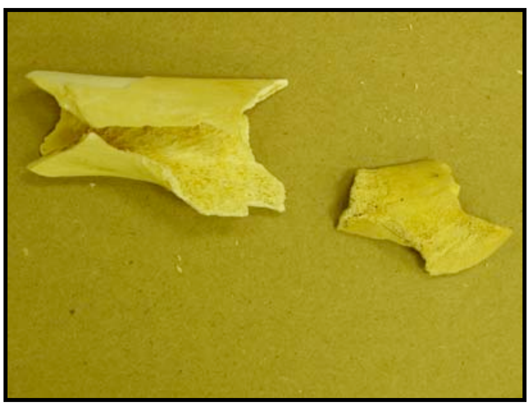

Figure 29. Right ilium (photograph by Chapman)

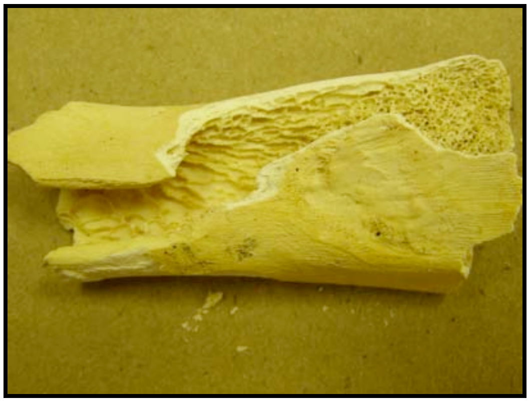

Figure 30. Left ischium (photograph by Chapman)

All of the ribs were recovered, analyzed, and described as damaged postmortem. The right second rib however, displayed trauma that was not a result of postmortem trauma (Fig. 31). The head of the rib was fractured transversely, immediately below the neck. On the shaft of the rib were three radiating fractures that began at the transverse fracture of the head, transecting the shaft into four sections. While the rib was completely recovered, it was no longer a whole unit.

Figure 31. Right fifth rib (photograph by Chapman)

Subject Two: .308 Winchester Rifle

Sixty bones were recovered from Subject Two. Twenty of the recovered bones (33.33%) were fractured from gunshot trauma and thirty-six (60%) were damaged postmortem (Table 3). The remaining four recovered bones (6.67%) were recovered undamaged.

The third, fourth, and fifth thoracic vertebrae were fractured transversely through the bodies. The third and fourth thoracic vertebrae also displayed small, oval-shaped compacted perforations through the proximal one third of the spinous processes (Fig. 32). The same wound was visible on the fifth thoracic vertebra, but appeared as a slight compacted fracture, only penetrating the superior wall. The first lumbar vertebra displayed a transverse fracture through the right inferior articular facet, as did the second lumbar vertebra through the right superior articular facet.

Figure 32. Third, fourth, and fifth thoracic vertebrae (photograph by Chapman)

The right scapula displayed multiple compacted and oblique fractures around the inferior margin and axillary border (Fig. 33). The main point of impact was indicated by a severely comminuted fracture and major bone loss, which was apparent on the associated radiographs and by physical examination (Fig. 34). There were many radiating fractures from this region throughout the body of the scapula. The glenoid fossa was fractured obliquely and demonstrated major bone loss.

Figure 33. Right scapula (photograph by Chapman)

Figure 34. Radiograph of shoulder wound (courtesy of the Bexar County Medical Examiner's Office)

Both humeri were damaged by gunshot trauma. In the right humerus, there was a complete, oblique fracture through the distal one third of the shaft, with radiating fractures throughout the distal epiphysis, trochlea, and capitulum (Fig. 35). The lateral side of the shaft displayed sharp, squared-shaped fractures, while the medial side was comminuted and jagged (Fig. 36). The left humerus displayed a main, spiral fracture through the distal one third of the shaft, with radiating fractures throughout the proximal and distal sections of the shaft (Fig. 37 and Fig. 38). The medial side of the shaft displayed sharp fracturing with a beveled side. The lateral side of the shaft was comminuted and jagged.

Figure 35. Right humerus, lateral view (photograph by Chapman)

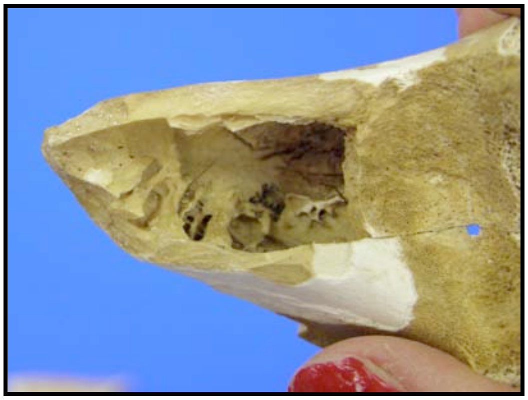

Figure 36. Right humerus, distal fracture section, medial view (photograph by Chapman)

Figure 37. Left humerus (photograph by Chapman)

Figure 38. Radiating fractures (photograph by Chapman)

The left innominate displayed fractures consistent with gunshot wounds, represented on the associated radiograph (Fig. 39). The left ilium was fractured longitudinally through the anterior side of the ala

(Fig. 40). A small portion of comminuted bone from the fractured ischium was also recovered (Fig. 41). No sections of the pubic bones were recovered.

Figure 39. Radiograph of pelvic wound (courtesy of the Bexar County Medical Examiner's Office)

Figure 40. Left ilium (photograph by Chapman)

Figure 41. Left ischial ramus (photograph by Chapman)

The left femur was fractured into multiple sections. Three radiating fractures traversed the length of the shaft towards the medial side and around to the inferior aspect of the shaft (Fig. 42). The lateral side of the shaft displayed comminuted fractures with associated bone loss.

Figure 42. Left femur (photograph by Chapman)

The left tibia was fractured longitudinally through the shaft (Fig. 43). There was some displacement of the sections of the bone, but all elements of the entire bone were recovered.

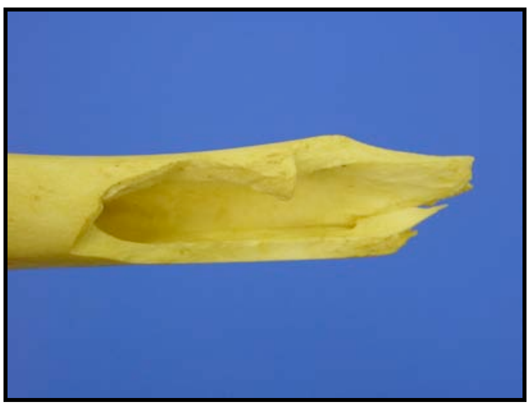

Figure 43. Left tibia (photograph by Chapman)

Gunshot trauma damaged six out of ten right ribs and three out of eight left ribs. From the right, the only portions recovered of the six ribs were the rib heads, which displayed spiral fractures below the neck. Radiating fractures traversed the remainder of the rib necks. From the left, the only portions recovered of the three ribs were the shafts. The neck of the fifth right rib was fractured obliquely, with minor radiating fractures.

Subject Three: 9mm Handgun, Hollow-point

Forty-four bones were recovered from Subject Three. Fourteen of the recovered bones (31.8%) were damaged due to gunshot trauma and twenty-seven (61.4%) were fractured postmortem (Table 4). Only three bones (6.9%) recovered were undamaged.

The bones between the ninth thoracic vertebra and the fourth lumbar vertebra were not recovered. The missing ten vertebrae might have been damaged beyond recovery from gunshot trauma or during processing. A proper analysis could not be made because it was not possible to conclude that the damage was a result of gunshot trauma or postmortem changes.

The shaft of the right humerus was recovered in multiple sections. The main point of impact was clearest on the anterior side (Fig. 44) and displayed an oblique fracture surrounded by five radiating, concentric fractures (Fig. 45).

Figure 44. Radiograph of right humerus wound (courtesy of the Bexar County Medical Examiner's Office)

Figure 45. Right humerus (photograph by Chapman)

The shaft of the right tibia was also recovered in multiple sections. The point of impact was on the anterior side, identified by the butterfly-shaped radiating fractures through the middle of the shaft (Fig. 46). Radiating fractures comminuted the shaft into multiple sections, through to the ends of the metaphyses (Fig. 47).

Figure 46. Radiograph of right tibia wound (courtesy of the Bexar County Medical Examiner's Office)

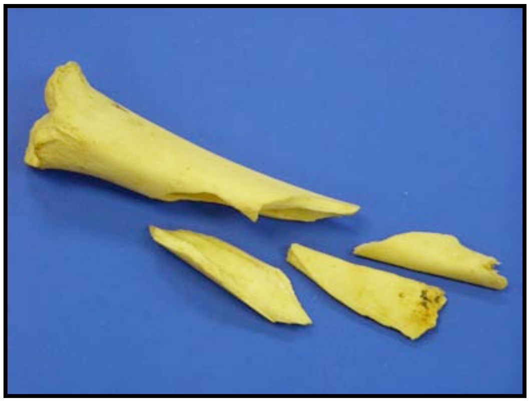

Figure 47. Right tibia (photograph by Chapman)

The right fibula displayed a spiral fracture at the proximal one third of the shaft. The proximal end of the bone was not recovered (Fig. 48).

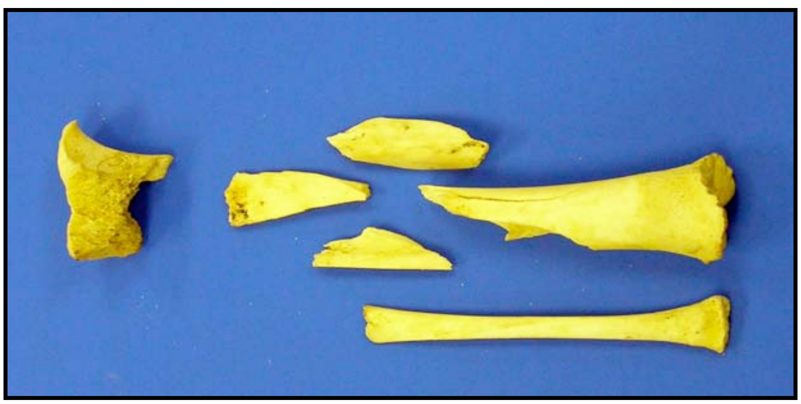

Figure 48. Right tibia and fibula (photograph by Chapman)

Five right ribs and eight left ribs were recovered. Three right ribs were damaged due to gunshot trauma, displaying radiating fractures traversing the length of the shaft. All eight of the recovered left ribs displayed similar fracture patterns of gunshot-related trauma .

Subject Four: 9mm Handgun, Hollow-point

All sixty-six bones were recovered from Subject Four. Nine bones (13.63%) were damaged due to gunshot trauma and twenty-four (36.36%) were fractured postmortem (Table 5). The remaining thirty-three bones (50%) recovered were undamaged.

Both right and left humeri were damaged by gunshot trauma. The right humerus was fractured into multiple sections at the mid shaft. The main proximal section displayed four radiating fractures that began around the point of impact and traversed to the humeral head (Fig. 49). The main distal section displayed three radiating fractures around that began around the point of impact and traversed to the epiphysis. On the lateral side of the right humerus, the point of impact was sharp and angled. The medial side displayed beveling and comminuted fractures with bone loss. The left humerus was also fractured around the mid shaft (Fig. 50). The main proximal section displayed five radiating fractures around the point of impact and directed toward the humeral head, while the main distal section was beveled on all edges. On the medial side of the left humerus, the point of impact was sharp and angled. The lateral side was severely beveled and comminuted.

Figure 49. Right humerus (photograph by Chapman)

Figure 50. Left humerus (photograph by Chapman)

The right femur displayed butterfly-shaped radiating fractures and was recovered in two complete sections (Fig. 51 and Fig. 52). The point of impact fractured the shaft through the distal one third, into proximal and distal sections. The main proximal section displayed three radiating fractures with beveled edges on the medial and posterior aspects (Fig. 53). The main distal section displayed one radiating fracture. On the anterior side of the femur, the point of impact was sharp, while the posterior side was beveled and minimally comminuted.

Figure 51. Right femur (photograph by Chapman)

Figure 52. Butterfly-shaped radiating fractures (photograph by Chapman)

Figure 53. Beveled edges of exit wound (photograph by Chapman)

The damage to the right tibia corresponded to the right femur, presented by a spiral fracture through the proximal one third of the shaft (Fig. 54), dividing the shaft into proximal and distal sections (Fig. 55).

The main proximal section was beveled on all sides. The remaining distal sections of the shaft displayed small, comminuted fractures that were sharp on all sides.

Figure 54. Radiograph of femur and tibia wounds (courtesy of the Bexar County Medical Examiner's Office)

Figure 55. Right tibia (photograph by Chapman)

All twenty-four ribs were recovered. From the right side, three ribs were damaged by gunshot trauma. The right fifth rib displayed butterfly-shaped radiating fractures through the proximal one third of the shaft, and the right sixth rib (Fig. 56) and twelfth ribs displayed butterfly-shaped radiating fractures through the mid shaft. From the left side, two ribs were damaged by gunshot trauma. The third rib displayed butterfly-shaped radiating fractures through the mid shaft, and the sixth rib displayed a spiral fracture through the proximal one third of the shaft (Fig. 57).

Figure 56. Right sixth rib (photograph by Chapman)

Figure 57. Example of spiral fracture (photograph by Chapman)

Subject Five: 9mm Handgun, Full metal-jacketed

Fifty-five bones were recovered from Subject Five. Four of the recovered bones (7.2%) were fractured due to gunshot trauma and forty-eight (87.3%) were fractured postmortem (Table 6). The remaining three recovered bones (5.5%) were undamaged.

The fifth thoracic vertebra displayed a transverse fracture through the midsection of the spinous process (Fig. 58), with radiating fractures through the body. No other vertebral damage could be related to gunshot trauma.

Figure 58. Fifth thoracic vertebra (photograph by Chapman)

The left humerus was severely damaged by gunshot trauma; the only portion recovered was the humeral head (Fig. 59). The fracture was severely comminuted and experienced a significant amount of bone loss.

Figure 59. Left humerus (photograph by Chapman)

There was also damage to the left ulna. The fracture was comminuted and the olecranon was compressed (Fig. 60).

Figure 60. Left ulna (photograph by Chapman)

Ten right ribs and three left ribs were recovered. The right fifth rib was damaged through the mid shaft. The anterior side of the fractured rib was sharp, while the posterior side was beveled and splintered. The fracture was comminuted and with a minor amount of bone loss (Fig. 61).

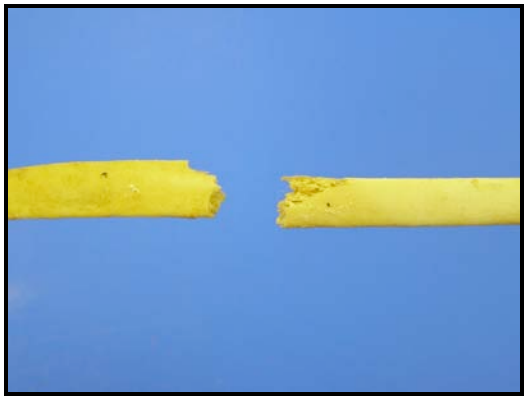

Figure 61. Right fifth rib (photograph by Chapman)

CHAPTER 6

DISCUSSION

Subject One: AK-47 Rifle

Direct evidence of one bullet was displayed by the trauma experienced to the right shoulder region. The right scapula displayed a comminuted fracture, with radiating fractures beginning at the point of impact. The bullet entered, directly impacting the vertebral border of the scapula, dispersing energy throughout. Trauma was extensive, localized, and consistent with the entrance of a high velocity bullet.

As a result, a great deal of the trauma also surrounded the chest cavity. The damage to thoracic vertebrae was consistent with the temporary cavity forces created by the entrance of the bullet in the shoulder region. There were multiple transverse and compacted fractures throughout these vertebrae. The right fifth rib also displayed fractures consistent with the point of impact described above. This rib was transversely fractured below the rib head, with radiating fractures traversing the shaft.

Once the bullet entered the shoulder region, a large quantity of energy was lost. The temporary cavity expanded, sending a shock wave of force to proximal regions of the wound. These forces caused consequential trauma of the vertebrae and rib.

Inferiorly, a second bullet entered the left innominate. While the pubic bones were not recovered, the surrounding patterns of trauma were consistent with a direct impact at this point. Both right and left ilia and the left ischium were spirally fractured from the forces of the temporary cavity. These fractures were sharp and simple rather than comminuted; patterns that indicated an indirect impact.

Examination of the thoracic and lumbar vertebrae at some distance from the point of impact still displayed trauma consistent with both indirect forces and direct forces of impacting secondary fragments. Because the trauma was distant, it was less sharp and clear, but still consistent with the temporary cavity forces created by the entrance of the bullet.

The amount of kinetic energy lost on impact from the high velocity rifle was tremendous. As soft tissue and bone from the impacted innominate moved away and created a temporary cavity, a wider region was damaged. The fourteenth thoracic vertebra, and the second, third, fourth, and fifth lumbar vertebrae displayed spiral fractures of the bodies, and small compacted and comminuted fractures of the body and transverse processes. The spiral fracturing of the bodies was a result of the shock wave of a nearby temporary cavity, while the compacted and comminuted fractures were a result of the direct impact of secondary fragments. The wide region of damage was a result of the expansive nature of the hollow-point bullet. The bullet passed through the pelvic region, expanding, and creating a cavitation effect. The explosive trauma affected a wide region, sending out secondary fragments of bone, tissue, and bullet jacketing as smaller but equally damaging missiles. The trauma from these missiles was presented as compact and comminuted fractures of the bodies and processes.

The damage displayed in Subject One was consistent with the known trauma sustained from a high velocity firearm loaded with hollow-point ammunition. The remains of Subject One were highly damaged, which is consistent with a high velocity rifle. The remains displayed both direct and indirect trauma in proximal regions of the original entrance wound, which is consistent with hollow-point ammunition. The damage to Subject One supported past research on gunshot trauma to soft tissues and crania, displaying these characteristics on the infracranium.

Subject Two: .308 Winchester Rifle

Direct evidence of one bullet was displayed by the trauma experienced to the right shoulder region. The right scapula displayed a highly comminuted fracture with radiating fractures traversing toward the axillary border. It is clear that this bullet directly impacted the region of the glenoid fossa because of the severe damage and radiating fractures.

The bullet also struck the right humeral head. The point of impact was indicated by a typical gunshot wound with clear entrance and exit wounds. The lateral aspect displayed the entry by a clean oblique fracture with sharp edges and the medial aspect displayed the exit by jagged edges and severe comminution. There were multiple radiating fractures traversing the entire length of the humeral shaft, terminating at the trochlea and capitulum. The trauma to the right shoulder region was consistent with direct impact from a hollow-point bullet fired at a high velocity. The fracture sustained to this area was more broad and 'explosive' than in Subject One; characteristics that signified a higher velocity firearm and expansive ammunition. The amount of kinetic energy lost was also much greater in Subject Two, which might be inferred by the severity of the trauma to the shoulder.

The left humerus also displayed an atypical fracture pattern associated with ballistics trauma. While the bullet itself did not directly strike this bone, the hollow-point bullet's expansion resulted in subsequent impact by projectiles of bullet jacketing and displaced bone and tissue. The characteristics of the fractured left humerus were quite similar to the right: one main, spiral fracture at mid shaft and two main sections of comminuted bone with traversing radiating fractures. However, a small distinction was clear in the left humerus – the appearance of a keyhole-like defect. While a keyhole defect generally appears when a bullet directly impacts the skull at a tangent, it is probable that similar mechanisms of trauma resulted in a keyhole-like defect to the left humerus of Subject Two.

Secondary fragments of bullet, jacketing, and bone displaced from the entrance of the bullet into the right humerus. One of the fragments then impacted the left humerus at such an angle that a wedge of bone levered upward with the forces of the moving fragment, leaving one edge of the fracture sharp like an entrance wound and the other beveled like an exit (Fig. 62). This characteristic is not normally attributed to the infracranium and has yet to be associated with impacting secondary fragments. However, keyhole fractures are a relatively rare occurrence in the cranium and are undocumented in the infracranium (c.f. Berryman and Gunther 2000). The defect to the left humerus is most likely a result of the same mechanisms that create cranial keyhole fractures, explaining their similar appearance. The fractures displayed on the left humerus are unique to trauma sustained by secondary fragments of bullet jacketing and displaced bone and tissue.

Figure 62. Keyhole-like defect (photograph by Chapman)

As a result of the shoulder wound, a great deal of the trauma surrounded adjacent vertebrae and ribs. The damage to the third, fourth, and fifth thoracic vertebrae was consistent with the temporary cavity forces created by the entrance of the bullet in the shoulder region. Both right and left ribs also displayed fractures characteristic of ballistics trauma that was consistent with the point of impact described above. It is important to note that while all of the ribs displayed spiral fractures below the rib head, the only rib heads that were found intact were from the right side and the only shafts recovered were from the left. This was likely a result of the random expansion of the hollow-point bullet once inside the chest cavity. Overall, the trauma to the vertebral column and ribs were consistent with the temporary cavity forces created by the entrance of the bullet in the shoulder region.

A second point of impact was visible in the left pelvic region. Similar to Subject One, Subject Two's pubic bones were not recovered. However, surrounding patterns of trauma were consistent with a direct impact at the junction of the inferior rami of the ischium and pubis. A small portion of bone from the left ischial ramus was recovered: the sharply beveled edges of each side indicated that this element came from a piece of comminuted fracture, resulting from a direct bullet impact. The left ilium was spirally fractured from the forces of the temporary cavity. This fracture is sharp and clean, patterns indicative of an impact in a proximal region. When reconstructing the remains of the innominates, a point of impact was clear on the left inferior region. The bullet expanded on impact, causing trauma to proximal regions of the pelvis.

Superiorly, examination of the lumbar vertebrae distant from the point of impact displayed trauma consistent with both indirect and direct forces of impacting secondary fragments. Because the trauma was distant, it was less sharp and clear, but still consistent with the temporary cavity forces created by the entrance of the bullet. As in Subject One, lumbar vertebrae displayed spiral fractures from shock waves of a nearby temporary cavity and compressed and comminuted fractures from direct impact of secondary fragments. One interesting fracture was located at the junction of the right inferior articular facet of the first lumbar vertebra and the right superior articular facet of the second lumbar vertebra. It was likely that a secondary fragment passed through this junction, fracturing both the first and second articular processes. The secondary fragments displaced from the entry wound created as much damage as the direct impact of the bullet.

A third point of impact was clear on the left femur. This bone displayed damage from secondary fragments from the pelvic wound and from a third bullet wound. From the pelvic wound, small compact fractures with short radiating fractures were apparent on the anterior side, mid shaft of the femur. The femur was distant from the direct impact site and these fractures were presented as minor depressions. The fragments traveled at a high velocity and lost enough kinetic energy to cause damage that was equivalent to the direct impact of a bullet, with associated radiating fractures.

Conversely, the entrance of a third bullet formed a major comminuted fracture on the medial side, mid shaft. The impact fractured the bone into two main pieces, with radiating fractures traversing the shaft. These fractures terminated at the compact fractures. While the femur experienced a great deal of bone loss, the remnant of butterfly-shaped radiating fractures was apparent. In this case, the forces of the moving projectile stressed the structure of the femur enough to cause radiating fractures around the point of impact.

The impact of the bullet on the left femur affected the left tibia as well. This bone displayed a simple spiral fracture at mid shaft with no bone loss. When the pieces of the shaft were rearticulated, there was no evidence of impact at any point. This fracture of the left tibia was consistent with the temporary cavity forces created by the entrance of the bullet in the left femur. It was likely that the fibula was not recovered because of this trauma.

Both Subjects One and Two were shot with high velocity rifles loaded with hollow-point ammunition. However, Subject Two displayed greater gunshot damage than Subject One. The ammunition fired at Subject Two was heavier and traveled at a significantly higher velocity than all of the subjects examined. The combination of these variables produced fracture patterns consistent with a greater loss of kinetic energy upon impact. The difference in detectable damage between Subjects One and Two was a direct result of these factors.

Subject Three: 9mm Handgun, Hollow-point

Direct evidence of the impact of one bullet was displayed on the right humerus. The shaft was obliquely fractured through the anterior side mid shaft, which was surrounded by multiple radiating fractures. While the shaft experienced some bone loss on both the anterior and posterior side, the slight remnant of a typical circular defect entrance wound was visible. Upon examination of the butterfly-shaped radiating fractures around the entrance and the comminuted, beveled fracture surfaces of the exit, it was clear that the bullet directly impacted the right humerus.

There was a clear distinction when comparing the damage on the right humerus of Subject Three to the damage on the right humerus of

Subject Two. Subject Two's humerus was virtually impossible to reconstruct, due to expansive fracturing and severe bone loss. Subject Three's humerus, on the other hand, was completely recovered and could be reconstructed. This difference was characteristic of the variable velocities and losses in kinetic energy of the weapons fired. The varying fracture patterns of Subjects Two and Three were indicative of either high or low velocity firearms, respectively, in spite of the similar ammunition used.

The right tibia displayed a second direct impact site, with similar fracture characteristics. In this case, the tibia was recovered in multiple sections. Upon reconstruction, it was possible to view the point of entrance on the anterior side, signified by an oblique fracture through mid shaft and butterfly-shaped radiating fractures from the point of impact. Comminuted fractures on the posterior side signified the exit of this bullet. Again, even though the bone was fractured into multiple pieces, the forces were low enough to permit complete reconstruction.

A spiral fracture of the right fibula was consistent with trauma caused by direct impact. If the tibia had been fractured by indirect forces or by direct impact of secondary fragments, the fibula would have displayed more damage. However, the point of impact was anterior, which sent a 'shock wave' towards the adjacent fibula, fracturing it sharply and cleanly.

A third impact point was viewed in the mid section of the torso. Both right and left ribs were recovered with radiating fractures traversing the entirety of the shafts. No proximal or distal ends were recovered from these ribs. Interestingly, the ninth through fourteenth thoracic vertebrae and the first through fourth lumbar vertebrae were not recovered, perhaps as a result of the bullet entering the lower stomach, impacting the posterior ribs and vertebrae, displacing tissue, bone, and bullet jacketing, and causing immense damage.

The damage displayed in Subject Three was consistent with trauma sustained from a low velocity firearm loaded with hollow-point ammunition. The amount of fracturing due to gunshot trauma in Subject Three was comparable to Subject Two. However, Subject Two was shot with a high velocity hunting rifle and Subject Three was shot with a low velocity pistol. Furthermore, the bullets fired at Subject Two were traveling at half the speed of the bullets fired at Subject Three, and impacted the carcass with nearly five times the kinetic energy.

The explanation for the similarities in trauma was a result of wound ballistics. The hollow-point bullets impacted Subject Three at such a low speed that an immense loss of kinetic energy affected a wide region with an explosive permanent wound track. The bullets fired at Subject Two, on the other hand, were traveling too quickly to affect as much space. The bullets fired at Subject Three were traveling slow enough to cause large temporary and permanent wound tracks. As a result, most of Subject Three's remains were either unrecoverable or severely damaged.

Subject Four: 9mm Handgun, Hollow-point

The impact of one bullet is evidenced on the right and left humeri. The bullet entered laterally into the right humerus, creating a clean permanent wound track. This was displayed upon reconstruction by a circular defect surrounded by radiating fractures. On the medial side, there was a clear permanent exit wound with comminuted, jagged fractures. While the bullet began to slow, yaw, and deform, it entered the left humerus. This permanent wound track was displayed as much more irregular. There was still a clear entry and exit, from medial to lateral, however both fractures were wider and more jagged. Even though the hollow-point ammunition was designed to expand on impact, there was not enough energy to display the 'explosion' seen in past subjects. Instead, enough energy remained for the bullet to penetrate both limbs, which displayed the deformation of the bullet as it moved through.

A second impact point was displayed on the right femur. The bullet's impact fractured the bone into two sections at the distal one third of the shaft. Again, it was possible to reconstruct the path of the bullet through the bone by examining the characteristics of the fractures. The bullet entered the femur shaft anteriorly, creating a clear circular entrance wound surrounded by butterfly-shaped radiating fractures.

The bullet exited the femur shaft posteriorly, displaying an irregular, beveled permanent wound track.

The right tibia was affected by the bullet's impact to the femur. While the sections of the fractured tibia were similar to the fractured femur, the fracture forming these sections was a result of indirect forces. The 'shock wave' sent from the formation of the temporary cavity spirally fractured the proximal one third of the shaft. While the remaining elements were comminuted, they were recovered and reconstructed. There was no evidence of direct impact at the point of fracture, supporting the fact that temporary cavity forces created by the entrance of the bullet into the right femur fractured the right tibia as well. The right fibula was also recovered in two sections, but does not display any of the characteristics of gunshot trauma.

Fractures relating to direct and indirect forces could be viewed on the right and left ribs. A third bullet was shot at the chest cavity and it penetrated and expanded on impact. While all twenty-four ribs were recovered, four displayed characteristic damage from the entrance of that bullet. The bullet entered the chest cavity on the right, impacting the sixth rib, and then expanded, damaging adjacent ribs. Upon reconstruction, the right sixth rib displayed a sharp entrance wound on the anterior side of the shaft. The posterior side displayed a jagged irregular exit wound. Conversely, the right fifth rib and the left third and sixth ribs displayed sharp spiral fractures of the shaft. It is interesting to note that not all of the ribs displayed fractures related to the shock wave sent through the chest cavity from the production of the temporary cavity. Also, there was no evidence of ballistics-related fractures on the adjacent vertebrae to support the exit of this bullet, which was likely due to its low energy on impact.

The damage displayed in Subject Four is consistent with trauma sustained from a low velocity firearm loaded with hollow-point ammunition. Subject Four displayed the least damage of the four subjects shot with hollow-point ammunition. Fifty percent of the remains that were recovered were completely undamaged, while the remaining fourteen percent of the recovered remains display damage related to ballistics trauma. Each direct impact wound was clearly visible as a permanent wound track with associating indirect trauma. This was directly related to the bullets' significantly less kinetic energy than present in the other subjects.

Subject Five: 9mm Handgun, Full metal-jacketed

The damage experienced from one bullet was visible on the fifth thoracic vertebra and the right fifth rib. The vertebra displayed a transverse fracture through the mid section of the spinous process, with fractures radiating in the direction of the body. This trauma was consistent with the right fifth rib, which was fractured at the mid section as well. This fracture displayed a permanent wound track, from posterior to anterior. The posterior side was sharp, while the anterior was beveled, jagged, and splintered. When the vertebral column and chest cavity was reconstructed, bullet direction could be predicted. The bullet first entered the chest, impacting the right fifth rib. The full metal-jacketed bullet did not expand and continued through the body to impact the spinous process of the fifth thoracic vertebra.

A second point of impact occurred at the left elbow region. Both the left humerus and left ulna were severely fractured by the bullet's permanent wound track. The humeral head and neck were the only elements of the humerus recovered. It was clear that this fracture was severely comminuted, as evidenced by the jagged and splintered fracture margins. This trauma was consistent with the ulna, which displays a compacted, transverse fracture below the olecranon. The olecranon itself was not recovered. Upon reconstruction, a clear pathway was visible and bullet direction was predicted. The bullet entered at the humeral-ulnar junction, impacting both bones. Again, the energy of the firearm and the full metal-jacketed bullet enabled complete perforation of the elbow region.

The damage displayed in the skeletal remains of Subject Five was consistent with trauma sustained from a low velocity firearm loaded with full metal-jacketed ammunition. Subject Five displayed less gunshot damage than any other subject. While kinetic energy of the bullets fired from this pistol was similar to the other subjects, the bullets' jacketing caused different fracture patterns. Full metal-jacketed ammunition, like the kind used on Subject Five, is designed to completely perforate a target without expansion or fragmentation. Because of the jacketing, the bullet moved straight through the carcass, leaving "textbook" indicators of entry and exit. All of the gunshot damage to Subject Five was consistent with directly impacting bullets.

CHAPTER 7

CONCLUSION

After complete examination of each subjects' skeletal remains, it was clear that there were significant differences observable in fracture characteristics and patterns. In particular, differences were viewed between the high velocity weapons (Subjects One and Two) and the low velocity weapons (Subjects Three, Four, and Five). High velocity weapons damaged bone more severely and irregularly, whereas low velocity weapons displayed clearer, less severe damage. Distinctions could also be made in the fracture characteristics of hollow-point ammunition (Subjects One, Two, Three, and Four) and full metal-jacketed ammunition (Subject Five). Hollow-point ammunition tended to expand upon impact in relation to velocity, damaging a variable amount of surrounding bone. This expansion caused characteristic damage from secondary fragments of tissue, bone, and bullet jacketing. Finally, each subject displayed differences of individual trauma sustained from directly impacting wounds versus those proximal to the point of impact. Directly impacting bullets formed circular defects associated with bullet entry and transverse, oblique, radiating, and comminuted fractures.

In general, the fracture surfaces were sharp and jagged, irregular, and splintered. Fractures formed through indirect impact were displayed as simple, clean spiral fractures.

Future applications

The most basic finding of this study is a re-emphasis on the importance of proper recovery techniques of all skeletal remains. This is absolutely critical in gunshot wound cases, where deductions can be made based on evidence found on minute elements of bone. Without each piece of the puzzle, a complete reconstruction of each bone and full understanding of its ballistics damage is rendered more difficult.

Furthermore, this study has demonstrated that certain assumptions cannot be made based solely on the skeletal evidence. While basic fracture patterns were described, there are many other variables involved in wound ballistics. The loss of kinetic energy is one trait involved in the production of trauma, dependent on the type of weapon and ammunition fired. Other variables in wound production are related to the yaw of the bullet on impact, and the type of tissue impacted.

In the past certain atypical defects, such as keyhole fractures were solely associated with the cranium. However, in this study, one long bone displayed similar features of a keyhole-like fracture, created by similar mechanisms. While the composition and morphology of the cranium is believed to be the influential factor in the production of this atypical defect, it might be possible that its production is affected by the direction and position of the bullet, body, and subsequently formed secondary fragments. However, this one example is not enough proof to change the determining characteristics of an understood pattern of trauma. The keyhole may be rare in appearance but it is important to keep in mind that atypical defects and all patterns of gunshot fractures are variable but crucial in determining perimortem ballistics trauma.

Suggestions

This study was preformed as a preliminary examination of gunshot trauma to the infracranial bones. There were no repeated measures, decreasing the possibility for the examination of statistical repetition and significance. Furthermore, the types of weapons and ammunition used in this study were not a complete representative sample of the firearms available in the United States. It is suggested that other types of rifles, handguns, and shotguns be tested to compile an index of the trauma sustained by gunshot. In addition to firearm types, the variation in ammunition must also be addressed. The weapons described above, and most others in the world, can be loaded and fired with a multitude of ammunition, both low and high velocity. Clinical and anthropological research has provided a basic understanding of the mechanisms of wound ballistics. However, gunshot trauma is highly variable and only comparable with known patterns at best. As researchers, it is important to identify the unique fracture patterns created by each bullet type and composition to gain a better perspective on gunshot trauma.

In addition to using a larger sample of weapons and ammunition, this type of research would benefit from being conducted with specialists who can measure and lend insight into the amount of yaw in flight or the exact point of impact and type of tissue struck, two of the determining factors in the loss of kinetic energy and resulting damage. Future studies could account for these variables if they are performed at a facility specifically equipped for ballistics research.

Concurrently, a designated decomposition and radiograph facility would also help decrease the amount of postmortem damage displayed by skeletal remains. Processing techniques must be modified in future studies in order to minimize postmortem damage. In this study, the remains were transported multiple times from the date of euthanization to the date of analysis. Radiographs were examined in order to account for possible confusion between gunshot and postmortem damage, however evidence may have been lost in the process. Diagnoses cannot be formed without direct examination of the bony elements. Again, future studies should be performed at a designated site or facility so that all aspects of the study can be completed at one location, with transportation of the remains minimized.

Table 2. Skeletal Analysis of Subject One

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Cervical Vertebrae				
C1	Complete - 2 sections	PM	Fractured through body	
C2	2 sections	PM	Broken off and missing body, dens, and spinous process	
C3	2 sections	PM	Broken off and missing most of body and spinous process	
C4	Right half	PM	Broken off and missing left body and spinous process	
C5	2 sections	PM	Fractured through body and missing spinous process	
C6	2 sections	PM	Fractured through body and missing spinous process	
C7	2 sections	PM	Fractured through body and missing spinous process	
Thoracic Vertebrae				
T1	Complete	PM	Fractured through body and the distal 1/3 spinous process. Chipping at superior, proximal portion of spinous process.	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
T2	Complete	GSW	Fractured through body and the distal 1/3 spinous process	Compacted, comminuted fracture with bone loss - due to "shock wave"
T3	Complete	GSW	Fractured through body and the distal end of spinous process. Chipping at inferior border of spinous process.	Compacted, comminuted fracture with bone loss - due to "shock wave"
T4	Complete	GSW	Fractured through body and distal spinous process.	Compacted, comminuted fracture with bone loss - due to "shock wave"
T5	Complete	PM	Fracture of spinous process at vertebral arch and distal 1/3.	
T6	Complete - 2 sections	PM	Right half - complete except for fractured proximal spinous process. Left half - Fractured at transverse process and body	
T7	Left half	PM	Fractured vertically throughout superior margin of midsection of spinous process	
T8	Complete	PM	Broken off and missing body and left transverse process. Damage to distal end of spinous process.	
T9	Left half and small element of right half	PM	Broken off and missing body and transverse processes. Some remnants of left body visible.	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
T10	Complete	PM	Broken off and missing body. Inferior articular facets and inferior portion of the spinous process remains. At midsection of spinous process, proximal end is vertically fractured and distal end is damaged.	
T11	Spinous process	PM	Broken off and missing body and transverse processes.	
T12	Complete	GSW	Broken off and missing body. Fractured through proximal spinous process.	Transverse and comminuted fractures - due to "shock wave"
T13	Complete - 2 sections	PM	Fractured through body. Broken and missing transverse processes. Inferior, proximal portion of spinous process is damaged.	
T14	Left half	GSW	Fractured through body, vertebral arch, and proximal 1/3 of transverse process.	Comminuted fracture with bone loss - direct impact of secondary fragments

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Lumbar Vertebrae				
L1	Complete - 2 sections	GSW	Fractured through body and inferior articular facet. Right transverse process fractured through at distal 1/3.	Transverse fracture, from anterior to posterior and impacted fractures - direct impact of secondary fragments
L2	Complete - 2 sections	GSW	Fractured through body and vertebral arch. Spinous process fractured at distal 1/3 and chipped on superior margin. Broken off and missing right superior articular facet. Left transverse process was fractured at proximal end. Right transverse process was fractured in half.	Transverse fractures, and compacted and comminuted fractures with bone loss - direct impact of secondary fragments
L3	Right half	GSW	Fractured through body and left transverse process. Fractured through vertebral arch and spinous process.	Spiral fractures - due to "shock wave"
L4	Right half	GSW	Fractured through body and left transverse process. Fractured through vertebral arch and spinous process.	Spiral fractures - due to "shock wave"
L5	Right half	GSW	Fractured through body	Longitudinal split - due to "shock wave"

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Scapula				
right	Complete	GSW/PM	(PM) Fractured midsection of superior margin and vertebral border, with axillary border remaining. (GSW) Radiating and secondary fractures at axilliary border.	Comminuted fracture with bone loss - direct impact
left	Complete	PM	Fractured superior and vertebral borders, with axillary border ramaining.	
Humerus				
right	Shaft	PM	Fractured at proximal and distal epiphyses.	
left	Shaft	PM	Fractured at proximal and distal epiphyses.	
Radius				
right	Shaft	PM	Fractured at proximal and distal epiphyses.	
left	Proximal 2/3	PM	Broken off and missing distal 1/3	
Ulna				
right	Proximal 2/3	PM	Broken off and missing distal 1/3	
left	Proximal 2/3	PM	Broken off and missing distal 1/3. Damaged olecranon.	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Pelvis				
Ischium				
right	Complete	PM	Fractured through pubic/ischial intersection. Damaged ischial tuberosity.	
left	Complete	GSW	Fractured through intersection of the inferior rami of the pubis and ischium.	Spiral fracture - due to "shock wave"
Ilium				
right	Complete - 2 sections	GSW	Fractured through ala	Spiral fracture - due to "shock wave"
left	Rectangular section of ala	GSW	Jagged fractures on all borders, with wedged fractured on inferior side	Piece of comminuted fracture - due to "shock wave"
Pubis				
right	NR			
left	NR			
Femur				
right	Shaft	PM	Fractured at proximal and distal epiphyses.	
left	Shaft	PM	Fractured at proximal and distal epiphyses.	
Tibia				
right	Shaft	PM	Fractured at proximal and distal epiphyses.	
left	Shaft	PM	Fractured at proximal and distal epiphyses.	
Fibula				
right	Shaft	PM	Fractured at proximal and distal epiphyses.	
left	Shaft	PM	Fractured at proximal and distal epiphyses.	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Ribs				
right	12 completely recovered	PM / 1 GSW	(PM) Fractured at multiple points on the rib shafts and through the heads. (GSW) 2nd rib displays radiating fractures at head and neck on the superior border.	Transverse fracture - due to "shock wave"
left	12 completely recovered	PM	Fractured at multiple points on the rib shafts and through the heads.	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

Table 3. Skeletal Analysis of Subject Two

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Cervical Vertebrae				
C1	Complete	PM	Fractured through body	
C2	Complete	PM	Broken off and missing dens. Fractured spinous process.	
C3	Complete	PM	Fractured through body and damaged on the right side.	
C4	Left half	PM	Broken off and missing spinous process and right half of body.	
C5	Left half	PM	Broken off and missing spinous process and right half of body.	
C6	NR			
C7	NR			
Thoracic Vertebrae				
T1	Complete	PM	Fractured through body. Chipping at the superior half of the spinous process.	
T2	Left half of body and transverse process, complete spinous process	PM	Fractured through body and vertebral arch on right side of spinous process.	
T3	Complete	PM/GSW	Fractured through body and on left side of spinous process adjacent to vertebral arch. Perforation through proximal 1/3 of spinous process.	Compacted and transverse fractures - due to "shock wave"

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
T4	Complete	PM/GSW	Fractured through body. Perforation through proximal 1/3 of spinous process.	Compacted and transverse fractures - due to "shock wave"
T5	Complete	PM/GSW	Fractured through body. Small penetration at proximal 1/3 on right side of spinous process. Chipping on superior margin of spinous process.	Compacted and transverse fractures - due to "shock wave"
T6	Complete	PM	Fractured through body	
T7	Complete	PM	Fractured through body	
T8	Complete	PM	Fractured through body and at proximal 1/3 of spinous process	
T9	Complete	ND		
T10	Complete	PM	Fractured through body	
T11	Complete	PM	Fractured through body and at proximal 1/3 of spinous process	
T12	Complete	PM	Fractured through body and at proximal half of spinous process.	
T13	Complete	ND		
T14	Complete	PM	Fractured through proximal 1/3 of right and left transverse processes	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Lumbar Vertebrae				
L1	Complete	PM/GSW	Fractured through proximal 1/3 of right and half of left transverse processes. Fractured through left inferior articular facet.	Transverse and spiral fractures - due to "shock wave"
L2	Complete	PM/GSW	Broken off and missing body and left superior articular facet.	Compacted and spiral fractures - due to "shock wave"
L3	Complete	PM	Fractured through body, spinous process, and transverse processes.	
L4	Complete	PM	Fractured through body, spinous process, and transverse processes.	
L5	NR			
Scapula				
right	Complete	PM/GSW	(PM) Fractured midsection of superior margin and vertebral border, with axillary border remaining. (GSW) Radiating and secondary fractures at inferior margin and axilliary border. Glenoid fossa broken off and missing.	Comminuted fractures with bone loss - direct impact
left	Complete	PM	Fractured on all borders	
Humerus				
right	Complete - multiple sections	GSW	Fractured through distal 1/3 with radiating fractures throughout distal portion (trochlea and capitulum)	Oblique fracture with comminuted and radiating fractures - due to direct impact

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
left	Complete - multiple sections	GSW	Fractured through distal 1/3 with radiating fractures throughout shaft, traveling both towards and away from the direction of fire.	Main spiral fracture with comminuted and radiating fractures, created appearance of keyhole-like entry wound at medial aspect - direct impact of secondary fragments
Radius				
right	Complete	ND		
left	Complete	PM	Broken off and missing distal epiphysis	
Ulna				
right	Complete	ND		
left	Complete	PM	Broken off and missing distal epiphysis	
Pelvis				
Ischium				
right	Complete	PM	Fractured at inferior border	
left	Ischial ramus	GSW	Fractures on all borders	Section of comminuted fracture - direct impact
Ilium				
right	Complete	PM	Fractured lengthwise through anterior side of ala	
left	Complete	GSW	Fractured lengthwise through anterior side of ala	Spiral fracture - "shock wave"
Pubis				
right	NR			
left	NR			

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Femur				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Multiple sections	GSW	Points of impact are most likely at medial and anterior half of shaft. Radiating fractures down length of shaft, towards medial point of impact, and on inferior aspect of shaft.	Comminuted fractures with bone loss - direct impact of bullet and fragments
Tibia				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	GSW	Fractured lengthwise down shaft.	Spiral fracture of the shaft. Some displacement of the sections but no bone loss - due to "shock wave"
Fibula				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	NR			
Ribs				
right	10 ribs completely	4 PM / 6 GSW	Heads found intact. Fractures at various sections of shafts.	Spiral fractures of necks and linear fractures at shaft - due to "shock wave"
left	8 ribs completely	5 PM / 3 GSW	Heads broken off and missing. Some ribs found with shaft fractures.	Spiral fractures at shaft and neck - due to "shock wave"

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

Table 4. Skeletal Analysis of Subject Three

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Cervical Vertebrae				
C1	Right half	PM	Broken off and missing body and spinous process	
C2	Right half	PM	Broken off and missing body and spinous process	
C3	Left half	PM	Broken off and missing body and spinous process	
C4	Left half	PM	Broken off and missing body and spinous process	
C5	Left half	PM	Broken off and missing body and spinous process	
C6	NR			
C7	Left half	PM	Broken off and missing body and spinous process	
Thoracic Vertebrae				
T1	NR			
T2	Spinous process	PM	Broken off and missing body and transverse processes	
T3	Right half	PM	Broken off and missing left half of body and left transverse process. Fractured through superior, distal 1/3 spinous process.	
T4	Complete	ND		
T5	Right half	PM	Broken off and missing left half of body, left transverse process, and spinous process.	
T6	Complete	ND		

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
T7	Complete	PM	Fractured through spinous process	
T8	Right half	PM	Broken off and missing left half of body, left transverse process, and spinous process.	
T9	NR			
T10	NR			
T11	NR			
T12	NR			
T13	NR			
T14	NR			
Lumbar Vertebrae				
L1	NR			
L2	NR			
L3	NR			
L4	NR			
L5	Complete - 2 sections	PM	Fractured through body	
Scapula				
right	Complete	PM	Fractured through supraspinatous fossa and superior border	
left	Complete	PM	Fractured through infraspinatous fossa and vertebral border	
Humerus				
right	Shaft - multiple sections	GSW	Fractured anteriorly through mid-shaft with five radiating fractures surround point of impact. Longest fracture on posterior side.	Oblique fracture with radiating fractures - direct impact
left	Shaft	PM	Fractured at proximal and distal epiphyses	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Radius				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	PM	Fractured at proximal and distal epiphyses	
Ulna				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	PM	Fractured at proximal and distal epiphyses	
Pelvis				
Ischium				
right	Complete	PM	Fractured at superior and inferior margins	
left	Complete	PM	Fractured at superior and inferior margins	
Illium				
right	Complete	PM	Fractured at superior and inferior margins, and lengthwise through posterior side of ala	
left	Complete	PM	Fractured at superior and inferior margins	
Pubis				
right	NR			
left	NR			
Femur				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	PM	Fractured at proximal and distal epiphyses	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Tibia				
right	Shaft - multiple sections	GSW	Fractured through mid-shaft. Point of impact on anterior side, with radiating fractures through to lateral condyle.	Oblique fracture and butterfly-shaped radiating fractures - direct impact
left	Shaft	PM	Fractured at proximal and distal epiphyses	
Fibula				
right	Distal 2/3	GSW	Fractured at proximal 1/3	Spiral fracture - due to "shock wave"
left	Complete	ND		
Ribs				
right	5 completely recovered	2 PM / 3 GSW	Radiating fractures run lengthwise.	Longitudinal splits - due to "shock wave." Corresponded to missing thoracic vertebrae.
left	8 completely recovered	GSW	Radiating fractures run lengthwise.	Longitudinal splits - due to "shock wave." Corresponded to missing thoracic vertebrae.

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

Table 5. Skeletal Analysis of Subject Four

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Cervical Vertebrae				
C1	Complete	ND		
C2	Complete	ND		
C3	Complete	ND		
C4	Complete	ND		
C5	Complete	ND		
C6	Complete	ND		
C7	Complete	ND		
Thoracic Vertebrae				
T1	Complete	PM	Broken off and missing body	
T2	Complete	PM	Broken off and missing body	
T3	Complete	PM	Broken off and missing body	
T4	Complete	PM	Broken off and missing body	
T5	Complete	PM	Broken off and missing body	
T6	Complete	ND		
T7	Complete	ND		
T8	Complete	PM	Broken off and missing body	
T9	Complete	PM	Broken off and missing body	
T10	Complete	ND		
T11	Complete	ND		
T12	Complete	ND		
T13	Complete	ND		
T14	Complete	ND		
Lumbar Vertebrae				
L1	Complete	ND		
L2	Complete	ND		
L3	Complete	ND		
L4	Complete	ND		
L5	Complete - 2 sections	PM	Fractured through body	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Scapula				
right	Complete	ND		
left	Complete	ND		
Humerus				
right	Complete - multiple sections	GSW	Fractured through midsection. Proximal section contained four radiating fractures around point of impact toward head of humerus. Distal section contained three radiating fractures around point of impact toward epiphysis.	Directional entry and exit beveling (from lateral to medial), comminuted fractures, and radiating fractures - direct impact
left	Complete - three sections	GSW	Fractured through midsections. Proximal section contained five radiating fractures around point of impact toward head of humerus. Distal sections were beveled on all edges and contain bullet wipe.	Directional entry and exit beveling (from medial to lateral), comminuted fractures, and radiating fractures - direct impact
Radius				
right	Complete	ND		
left	Complete	ND		
Ulna				
right	Complete	ND		
left	Complete	ND		
Pelvis				
Ischium				
right	Complete	ND		
left	Complete	ND		
Ilium				
right	Complete	ND		
left	Complete	ND		
Pubis				
right	Complete	ND		
left	Complete	ND		

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Femur				
right	Complete - two sections	GSW	Fractured through distal 1/3, entry at anterior, exit at posterior. Proximal section contained three radiating fractures with beveled edges on medial and posterior aspects. Distal section contained one radiating fracture and beveled edges on medial and posterior aspects.	Directional entry and exit beveling (from anterior to posterior), butterfly-shaped radiating fractures - direct impact
left	Complete	ND		
Tibia				
right	Complete - multiple sections	GSW	Fractured through proximal 1/3. Proximal section was beveled on all edges. Other distal sections were small and broken.	Main spiral fracture, with comminuted fractures surrounding distal portion - due to "shock wave." After reassembling comminuted pieces, no point of impact could be established.
left	Complete	ND		
Fibula				
right	Complete - two sections	PM	Fractured through proximal 1/3.	
left	Complete	ND		

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	TYPE
Ribs				
right	12 completely recovered	9 PM / 2 GSW	Fifth rib: fractured through proximal 1/3. Sixth rib: Fractured through midsection. Twelfth rib: fractured through midsection.	Butterfly-shaped radiating fractures from greenstick-like forces - direct impact
left	12 completely recovered	10 PM / 2 GSW	Third rib: fractured through midsection. Sixth rib: fractured through proximal 1/3.	Butterfly-shaped radiating fractures - direct impact and spiral fractures - due to "shock wave"

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

Table 6. Skeletal Analysis of Subject Five

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	GSW FRACTURE TYPE
Cervical Vertebrae				
C1	Left half	PM	Broken off and missing body and spinous process	
C2	Complete	PM	Fractured through body	
C3	Right transverse process and spinous process	PM	Broken off and missing body and left transverse process	
C4	Right transverse process and spinous process	PM	Broken off and missing body and left transverse process	
C5	Right transverse process and spinous process	PM	Broken off and missing body and left transverse process	
C6	Right transverse process and spinous process	PM	Broken off and missing body and left transverse process	
C7	Right transverse process and spinous process	PM	Broken off and missing body and left transverse process	
Thoracic Vertebrae				
T1	Spinous process	PM	Broken off and missing body and transverse processes	
T2	Spinous process	PM	Broken off and missing body and transverse processes	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	GSW FRACTURE TYPE
T3	Left transverse process and spinous process	PM	Broken off and missing body and right spinous process	
T4	Complete	PM	Fractured through body	
T5	Complete	GSW	Fractured through midsection of spinous process, with radiating fracture toward body.	Transverse and radiating fractures - direct impact
T6	Complete	PM	Fractured through body	
T7	Complete	PM	Fractured through body	
T8	Complete	PM	Fractured through body	
T9	Spinous process	PM	Broken off and missing body and transverse processes	
T10	Complete	PM	Fractured through body	
T11	Complete	PM	Fractured through body	
T12	Complete	PM	Fractured through body	
T13	Complete	PM	Fractured through body	
T14	Right half	PM	Broken off and missing body and left transverse process	
Lumbar Vertebrae				
L1	Complete	PM	Fractured through body	
L2	Complete	PM	Fractured through body	
L3	Complete	PM	Fractured through body	
L4	Complete	PM	Fractured through body	
L5	Complete	PM	Fractured through body	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	GSW FRACTURE TYPE
Scapula				
right	Complete	PM	Fractured through superior border, axillary margin, and spine.	
left	Complete	PM	Fractured through superior border, axillary margin, and spine.	
Humerus				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Head	GSW	Broken off and missing shaft and distal section	Comminuted, with complete bone loss - direct impact
Radius				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	PM	Fractured at proximal and distal epiphyses	
Ulna				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Complete	GSW	Olecranon appears crushed	Severely comminuted - direct impact
Pelvis				
Ischium				
right	Complete	ND		
left	Complete	ND		
Illium				
right	Complete	ND		
left	Complete	ND		
Pubis				
right	Complete	ND		
left	Complete	ND		

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

SKELETAL ELEMENT	RECOVERED PORTION	DAMAGE	LOCATION	GSW FRACTURE TYPE
Femur				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	PM	Fractured at proximal and distal epiphyses	
Tibia				
right	Shaft	PM	Fractured at proximal and distal epiphyses	
left	Shaft	PM	Fractured at proximal and distal epiphyses	
Fibula				
right	Shaft	ND		
left	Distal 2/3	PM	Fractured through proximal 1/3	
Ribs				
right	10 completely recovered	9 PM / 1 GSW	Fifth rib: fractured midsection	Entry and exit bevels, jagged splintering, along with bone loss - direct impact
left	3 completely recovered	PM	Fractured lengthwise along shaft, fractured head and neck	

NR = Not recovered **PM = Postmortem damage**
ND = No damage **GSW = Gunshot wound damage**

APPENDIX A

INFRACRANIAL BONES

Element		Total
Cervical vertebrae	C1 – C7	7
Thoracic vertebrae	T1 – T14	14
Lumbar vertebrae	L1 – L5	5
Scapula	Right/left	2
Humerus	Right/left	2
Radius	Right/left	2
Ulna	Right/left	2
Pelvis	Right/left	2
Femur	Right/left	2
Tibia	Right/left	2
Fibula	Right/left	2
Ribs	12 right/ 12 left	24

66 total skeletal elements.

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