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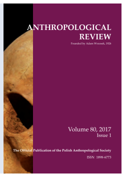

Anthropological analysis of projectile trauma to the bony regions of the trunk

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Abstract: Ballistics literature often focuses on soft tissue injures and projectile trauma to the cranium. Minimal details on the bony characteristics of projectile trauma to the thorax/abdomen regions have been published. This study aims to analyse projectile trauma to the bony trunk region including the ribs, vertebrae, scapula, sternum and the hip bone to form a better understanding of the characteristics and biomechanics of skeletal trauma caused by a projectile and contribute to the existing database on skeletal trauma caused by projectiles. Fourteen cases of documented projectile trauma to the bony regions of the trunk from the Hamman-Todd Human Osteological Collection at the Cleveland Natural History Museum, Ohio were analysed. Of the 14 individuals with gunshot wounds examined, 40 wounds occurred to the bones. Twenty-four injuries to the ribs, 1 ilium, 11 vertebrae, 3 scapulae, and 1 sternum. Fracture patterns, heaving and bevelling can be used to determine the direction of travel of the projectile which can be evident on the ribs, sternum, scapula and ilium. It is critical to understand the wounding patterns associated with projectile trauma to the torso region as this is often targeted, due to being the centre of mass.

Key words: thorax; bullet trauma; fracture; bone trauma; ribs; ballistics injury

Introduction

Much research in ballistics has focused on soft tissue injuries including autopsy features and experimental aspects utilising animal models, ballistics simulants and dummy models (Bir et al. 2016; Humphrey et al. 2017; Humphrey and Kumaratilake 2016; Jönsson et al. 1988; Mabbott et al. 2016; Schantz 1978). When it comes to bony injuries from projectiles, a lot of research has been conducted into maxillofacial ballistics trauma (Berryman et al. 1995; Lahren et al. 1987; Stefanopoulos et al. 2015; Viel et al. 2009). The literature has been able to document the characteristics of projectile skeletal trauma to the skull as well as soft tissue characteristics, however minimal details on the thorax/abdomen bony regions in particular the scapula, ribs, sternum and vertebrae have been published (Langley 2007).

In 1995, Ubelaker (1995), published an anthropological analysis of an individual who was assassinated sustaining gunshot trauma. The analysis produced

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evidence for projectile path and thus direction of fire based on the displacement of bone fragments, fractures, bevelling and appearance of the fractures. More recently, Langley (2007), produced an anthropological analysis of gunshot wounds to the chest region with the focus on assessing the usefulness of the characteristics of the wounds in determining the direction of fire. Using 54 documented cases of gunshot wounds to the thorax, Langley (2007), found that due to the ribs occupying a significant portion of the thorax, they were commonly hit by a projectile and that the bullets leave distinctive marks on ribs which are able to determine the direction of fire. Langley concluded that further analyses of the bony structures of the thorax are needed to get a better understanding of the biomechanics associated with bony projectile trauma to the thorax. Most forensic anthropology text books also describe bone trauma from projectiles (Byers 2015; DiMaio 2015; Dirkmaat 2014). Many other researchers have investigated the biomechanics of gunshot wounding, characteristics of wounds caused by different projectiles, how low velocity projectiles cause injury, prediction of the calibre of the weapon and manner in which death occurred (Berryman et al. 2012; Berryman and Symes 1998; de la Grandmaison et al. 2001; DiMaio 2015; Lahren et al. 1987; Langley 2007; Smith and Wheatley 1984; Spitz and Spitz 2006). However, misinterpretations have been noted, thus there is a need to understand the relationships between soft and hard tissue trauma injuries (Fackler 1987; Fackler 1988). Symes et al. (2012), have suggested that the interpretation and assessment of high velocity impact to osseous tissue is only in its early stages and therefore more research is necessary to properly understand and accurately interpret the bone injuries resulting from projectiles.

This study aims to analyse projectile trauma to the bony trunk region including the ribs, vertebrae, scapula, sternum and the hip bone to form a better understanding of the characteristics and biomechanics of skeletal trauma caused by a projectile. This study will contribute to the existing literature on skeletal trauma caused by projectiles.

Materials and Methods

The Hamman-Todd Human Osteological Collection at the Cleveland Natural History Museum, Ohio, contains 44 documented cases of gunshot trauma. Two cases had been returned to their respective families; twelve had unknown location of wound or not visible wound (i.e. soft tissue trauma only); 3 had wounds to the limbs; thirteen had wounds to the cranium and fourteen had wounds to the torso region, that were sustained in real life situations. The fourteen torso region cases are discussed here. Each case was documented as gunshot wound being the cause of death, and where known, the manner of death was also documented (4 homicide, 10 unknown). The age and sex were noted from the Museums records (mean age 29.86 (SD 7.57); sex: female 14.2%, male 85.7%). Causative weapon was not known in the cases; however, no shotgun injuries were present due to the unique wounding properties of these types of weapons. Shots expelled from such a firearm form a large cloud of pellets that expands in diameter as distance increases. Due to the small size of each pellet, its kinetic energy is low and therefore one could expect multiple low impact injuries.

A visual examination of the entire skeleton (where present) occurred to determine the location of the wounds. A Canon 5D Mark III with macro lenses camera was used to photograph the wounds. No autopsy records or pathologists evaluations were available to assess soft tissue details, thus only anthropological analysis of the wounds occurred.

Results

Of the 14 individuals with gunshot wounds examined in this study, 40 wounds occurred to the bones. Twenty-four injuries to the ribs, 1 ilium, 11 vertebrae, 3 scapulae, and 1 sternum.

Fig. 1. Vertebrae of Individual HTH 524, displaying 7th, 8th and 9th vertebral body shattering

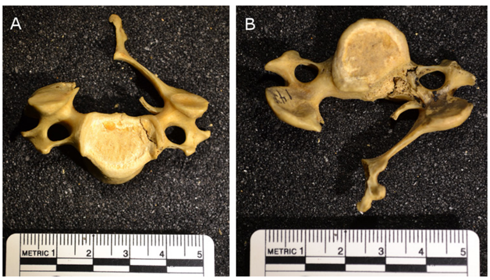

Fig. 2. Vertebra of Individual HTH 1430, displaying clear fracture and missing segment of cervical vertebra (A, B)

Vertebrae

In the vertebrae, the injuries were often a shattering of the vertebral body, small clear fractures, and missing segments of bone including the pedicle. This occurs in the cervical, thoracic and lumbar vertebrae (Figures 1–4).

Fig. 3. Vertebrae of Individual HTH 1812, displaying fracture and missing segments of Lumbar 4

Fig. 4. Vertebrae of Individual 659, displaying vertebral shattering of thoracic 3, 4, 5 and 6 (A, B)

Sternum

The sternum, particularly the corpus sterni (Figure 5), showed both an entry and exit wound which were distinguishable from each other, thus the ability to determine the projectile path. The entry wound was smaller with radiating fractures. The exit wound, larger and more irregular in shape, also produced radiating fractures, however these heaved outwards.

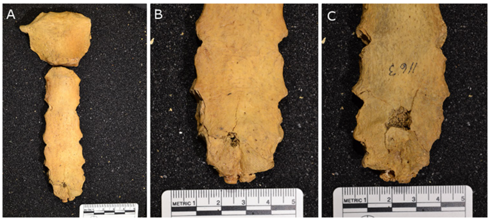

Fig. 5. Sternum of Individual HTH 1163. Full sternum displaying entry wound (A), entry wound (B), and exit wound (C), with small radiating fractures

Ribs

The ribs showed varying types of wounds. The first being small nicks in the bone as the projectile passed and minimally made contact with the bone. These present as semi-circular/oval defects on either the caudal or cranial edge of the ribs (Figures 6, 7, 8, 9, 10, 11). The diameter of the wound may reflect the calibre of the

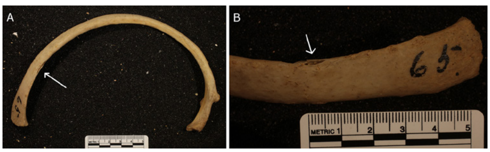

Fig. 6. Superior view of Individual HTH 65 right 4th rib (A) with arrow indicating wound on cranial edge of the sternal end. Close view of the wound (B), indicated by arrow

Fig. 7. Inferior view of Individual HTH 65, left 4th and 5th rib (A), with arrow indicating wound on caudal edge of sternal end of 4th rib. Close view of wound (B)

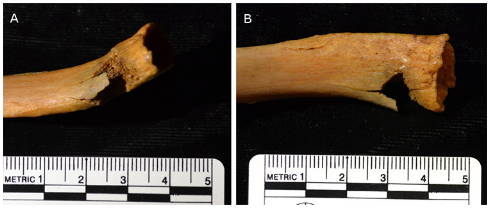

Fig. 8. Individual HTH 1662, displaying circular defect in sternal end, caudal edge with flaking inwards (A, B)

Fig. 9. Right 8th rib of individual HTH 596 (A). Wound located on cranial edge on articulating end of rib. Fractures running along length of rib in spiral pattern (B), and the clear circular entry wound (C)

Fig. 10. Individual HTH 1238 left 9th rib displaying bone nick on cranial edge with depressed bone (A, B), and small radiating fractures lifting outwards (B)

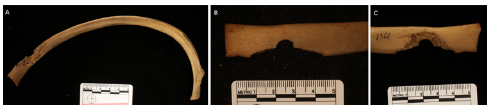

Fig. 11. Individual HTH 1361. Left 3rd rib displaying circular defect on sternal end, caudal edge (A). Clear circular entry with missing segments (A), external bevelling and flaking of exit wound (B)

bullet, being large or small, however, such evidence is not definitive. The second type are fractures on either the sternal or vertebral end of the rib. These fractures run along the length of the rib (Figures 12, 13).

Fig. 12. Individual 524 displaying fracture running along length of rib on caudal edge of articulating end

Fig. 13. Individual HTH 2104. Right 5th and 6th ribs with fractures running along cranial surface edge of sternal end (A). Left 1st rib displaying small notch, and other rib with damage to sternal end

Fig. 14. Individual HTH 1361. Right 6th rib displaying fracture through shaft bending laterally

Fig. 15. Individual 1238 right 3rd rib. Caudal edge on articulating end displaying oval defect with radiating fractures similar to a butterfly pattern seen in long bone fractures

Other fractures can occur mid-shaft, often fracturing a rib completely into separate pieces, two or more which can be reconstructed (Figure 14). The third is a combination of a small circular nick in the bone, with fractures that run along the edge of the rib, some appearing similar to spiral fracture patterns (Figures 8, 9). What has been referred to as butterfly fractures in long bones, may also occur in these types of rib fractures (Figure 15). When the circular defect is present, the entry and exit side may be distinguished with the use of bevelling on the exit wound, entry wound is circular and smaller than the exit, depressed or heaving fractures (Figure 8, 9, 11). Multiple fractures may appear in the same individual, which can be difficult to distinguish as peri- or post-mortem (Figure 16, 17). These fractures can be simple transverse fractures across the width of the rib, or run along the rib, as in oblique fractures. If the bullet arrests in the rib, it may form a wound similar to Individual HTH 985 (Figure 18), where the bone remodels around the bullet (as would occur if the bullet was not removed and the patient survived).

Fig. 16. Individual HTH 1163 displaying commingled ribs with various fractures with no clear entry or exit wounds

Fig. 17. Individual HTH 659. Fracture of left 3rd rib through shaft (A, B). Right 2nd, 3rd, 4th ribs with no distinct entry or exit wounds but fractures through shaft (C). Left 2nd rib with fracture through and along shaft (D)

Fig. 18. Individual HTH 985. Wound on right 7th rib. Potentially due to bullet arresting in rib and bone displaying signs of remodelling around bullet

Scapulae

Due to the irregularity and non-uniform thickness of the scapula, the wounds vary. The three injuries to the scapulae

Fig. 19. Individual HTH 659 with circular wound in subscapular fossa with fracturing

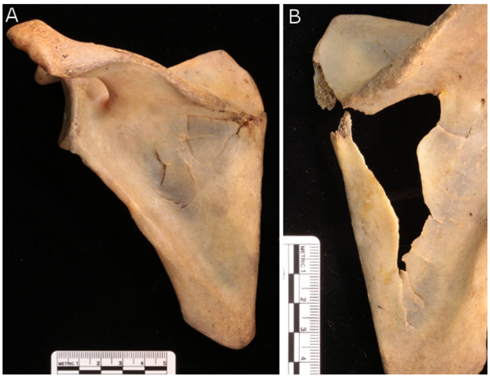

Fig. 20. Individual HTH 1709. Left scapula with damage to infraspinous fossa (A), while right scapula shows damage to infraspinous fossa and vertebral border of scapula spine and missing segments (B)

in this study showed that when a bullet penetrates the subscapular fossa (Figure 19) a clear circular wound is visible but fracturing into segments occurs. In individual HTH 1709 (Figure 20), both the left and right scapulae were injured. The fracturing pattern on the left scapula shows in the infraspinous fossa fractured fragments heaving in the dorsal direction. The right scapula shows similar fracturing of the fragile and thin infraspinous fossa as well as the vertebral border of the scapular spine. In this individual, no clear entry or exit wound was visible. Most likely the projectile entered the thorax anteriorly and caused cavitation that produced injuries to both scapulae.

Ilium

The ilium also showed distinct entry and exit wounds. The entry was oval in shape with depressed bone fragments and small radiating fractures. The exit wound, had significant external bevelling.

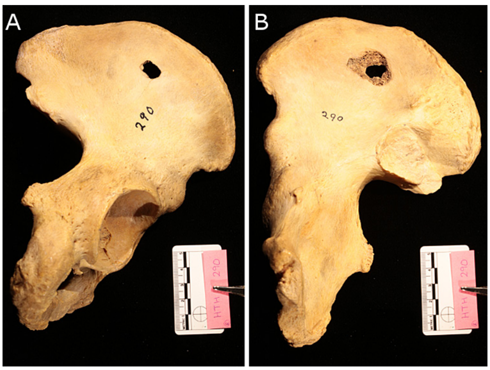

Fig. 21. Individual HTH 290 with wound on left ilium displaying circular wound (A), and clear exit wound with external bevelling (B)

Discussion

When firing a weapon at an individual, the majority of people will aim for the centre of mass, this being the thorax and abdomen region or torso. In classical training of military and police, the trainees are instructed to aim at the centre of mass of the body, which is located in the torso region. Within the torso are major organs and thus death is highly likely. However, along with the soft tissues, there are also bony structures including the sternum, vertebrae, ribs, scapula, clavicle and lower down the pelvis. The projectile is therefore often to produce skeletal trauma to these regions in the victim. However, it has been found that a bullet can pass through the intercostal spaces without leaving evidence on the bone (Langley, 2007). The analysis of soft tissue, when available, can determine many details about an individual's death, however, the analysis of the skeletal elements by a forensic anthropologist can provide additional support and is critical when only skeletal material is available.

Unlike soft tissues, bone offers more resistance against penetration by a bullet due to its composition, hardness, density and strength (Bartlett 2003; Janzon et al. 1997; Stefanopoulos et al. 2015). Due to its nature, bone tissue cannot absorb the energy transferred from a bullet to the extent in which soft tissues do. Instead, bones act like a brittle material (Kieser et al. 2014; Stefanopoulos et al. 2015), when the stress/strain is beyond that they can rebound from, fractures occur. Ballistics fractures fall within sudden force and high speed category (Chapman 2007; Hamblen et al. 2007), and such fractures could result from direct impact of projectiles with excessive speed or a projectile at a vulnerable point in the bone (Byers 2015; Chapman 2007). The force exerted must be greater than what the bone can withstand and often occurs with projectiles moving at velocities ranging between 61 and 171 metres per second. When this occurs, the bone will fracture (DiMaio 2015; Harvey et al. 1962; Sellier and Kneubuehl 1995). Huelke et al. (1968) found that for visible damage of the bone, a velocity of 213.36 m/s or more was required.

The skeletal wounding potential of a projectile will depend on numerous factors associated with the projectile itself as well as the bone which it makes contact with. These will affect the characteristics of the injury. The type of bone which the bullet contacts will affect the characteristics of that injury. Bone consists of, on a molecular level, collagen and a calcium phosphate (hydroxyapatite) which give it its flexibility, strength and rigidity. Bone can be categorised according to the shape (i.e. long, short, flat, irregular). Projectile injuries to the flat bones, such as the cranial vault, have the distinguishing feature of bevelling which can determine the entry and exit wound (Chapman 2007; DiMaio 2015; Quatrehomme and İşcan 1997, 1998a,b, 1999). The ribs have an oval elongated cross-section, and contain some tubular properties, although the entire inside of the rib is comprised of trabecular spongy bone. Wounds in the ribs may also show bevelling or flaking in the direction of bullet travel, as seen in (Figures 8, 11, 14). This bevelling appearance of wounds is critical in determining the direction of travel of a bullet, and as seen in this study, can be seen in the ribs (Figure 8, 11, 14), sternum (Figure 5), ilium (Figure 21). It is less seen in the scapula (Figure 19, 20), potentially due to the thin nature of this bone compared to the thicker sternum which has a greater trabecular bone content (Tersigni-Tarrant and Shirley 2012).

The direction in which the force of the bullet penetrates the bone will also determine the characteristics of the wounds. If a bullet penetrates the thorax cavity, travelling through the intercostal spaces, no bone defects may appear. However, if the bullet contains a significant amount of energy which is deposited into the surrounding tissues by Newtons Laws, a temporary cavity will occur which may cause fractures in the midshaft of the ribs (Figures 14, 16, 17). Unlike in soft tissues, the temporary cavity in bone tissue is not followed by the collapse of the cavity, rather the lack of elasticity causing a pulverisation effect to the bone (i.e. fracture) (Huelke et al. 1968; Janzon et al. 1997; Stefanopoulos et al. 2015). The transfer of energy to bone in ballistic injuries is less understood (Kieser et al. 2014; Molde and Gray 1995; Stefanopoulos et al. 2015), in comparison to that in soft tissues. The soft tissues, due to their elastic properties, are able to absorb the energy transferred and revert back to their normal state, unless their elasticity is overcome. In bones, this elasticity value is less than that in soft tissues i.e. less energy is required to fracture the bone and it acts in a brittle manner. The amount of energy transferred to bone is influenced by the amount of contact time between the bullet and the bone, and this is inversely proportional to the velocity. Thus, a bullet travelling with low velocity will have more contact with the bone compared to a high velocity bullet and therefore it is possible for these slow bullets to cause more damage (Rothschild 2011; Stefanopoulos et al. 2015). However, high velocity bullets can have an explosive effect where when penetrating soft tissues indirect fractures are caused to nearby bones (e.g. ribs or long bones) due to the expansion of the temporary cavity and the transfer of high energy (Clasper 2001; Hollerman et al. 1990; Humphrey and Kumaratilake 2016; Janzon 1983; Mellor 1994; Stefanopoulos et al. 2015).

A bullet may also contact the bone at an angle, such as with the scapula (Figure 20), and the bone will fracture in a comminuted way. When this occurs, the way the bone fractures (e.g. heaves outwards) can be used to determine the direction in which the bullet travelled. When the bullet penetrates any bone perpendicular to the surface, it is highly likely that the bullet will completely penetrate the bone, and a clear entry/exit wound will appear. This could occur here in the sternum (Figure 5), scapula (Figure 19), ilium (Figure 21). When the bullet penetrates the ribs, perpendicular, it may not make contact with the whole rib and therefore produce a nick in the rib. This nick will be oval/circular in shape, mimicking the shape of the bullet (Figures 6–11). If high energy, the rib may also fracture along the length of the rib (Figure 9, 12, 13, 15).

Fractures in the ribs, and also the vertebrae, may also be due to the passing of a bullet in close proximity to the bones, however not directly penetrating them. This would possibly only occur if the energy of the bullet is high enough to transfer the energy to the surrounding tissues and overcome the strength of the bone. With the vertebrae, as also found by Langley (2007), there is no clear entry or exit wounds, and the vertebral body often is comminuted (Figures 1–4). Secondary missiles occur when minute fragments from the impacted bone cause their own permanent cavity. This can also occur with fragmenting bullets. This causes further trauma to other portions of the body that can magnify the damage beyond that of the simple drilling effect of the bullet itself (Harger and Huelke 1970). These are most often seen through radiographic studies (Amato et al. 1989). It has been found through experimental studies that the secondary fragments (e.g. bullet fragments, jacketing and bone shards) have the same possibility of lethality as the original bullet. The amount of damage increases if the impact velocities are great (i.e. 243 m/s) (Harger and Huelke 1970). It could be presented as jagged edges, blown out fracture edges, large quantities of bone loss (Robens and Küsswetter 1982).

The fractures to the ribs may also be able to be described by the general types of fracture terminology based on the pattern of the fracture which reflects the type of force acting on the bone. For example, transverse fractures where the bone fractures perpendicular to its long axis under tension occur often (Figure 16, 17), oblique fractures where a 45 degree angle to its long axis under bending and compression occurs (Figure 17), spiral fractures, often occurring in long bones, have been noted in the rib cases (Figure 9). As ribs and shafts of long bones have a shape of oval tube, the force acting on these bones in torsion will create an oblique-like fracture which encircles the axis of the ribs. An interesting find was in one case (Figure 15) where a fracture similar to a butterfly fracture occurred. The bone is penetrated by a bullet, where the force is a combination of tension, compression and bending creating a nick in the bone directly from the bullet and a triangular fragment and two segmented pieces (Figure 15). This often occurs in long bones (Symes et al. 2012) and in blunt force trauma. The force acting in this type of wound produces angulation fractures (Ubelaker 1995).

As with gunshot wounds to the cranium, bevelling is a distinguishing feature of entrance and exit wounds. This characteristic has been seen here on some of the ribs (Figure 11) as well as on the ilium (Figure 21). The heaving of a fracture in a particular direction or displaced fragments of bone can also determine the direction of travel (e.g. Figure 14).

Conclusion

It is critical to understand the wounding patterns associated with projectile trauma to the torso region as this is the centre of the mass and is often targeted. The fracture patterns on the ribs can be used to determine the direction of travel of the projectile. Further analysis of more specimens will provide a greater understanding of these wounding patterns and controlled experimental studies may lead to the development of a bone simulant which is able to be used in these experiments.

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Authors' contributions

CH collection of data, analysis and interpretation of wound trauma, concept, writing and finalising article, approval of final article version; MH interpretation of wound trauma, critical revision and drafting of article, approval of final article version.

Conflict of interest

There are no conflicting interests.

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References

Amato JJ, Syracuse D, Seaver PR, Rich N. 1989. Bone as a secondary missile: an experimental study in the fragmenting of bone by high-velocity missiles. J Trauma Acute Care Surg 29(5):609–12.

Bartlett CS. 2003. Clinical update: gunshot wound ballistics. Clin Orthop Relat R 408:28–57.

Berryman HE, Smith O, Symes SA. 1995. Diameter of cranial gunshot wounds as a function of bullet caliber. J Forensic Sci 40(5):751–54.

Berryman HE, Symes SA. 1998. Recognizing gunshot and blunt cranial trauma through fracture interpretation. In: CC Thomas, ed. Forensic osteology: advances in the identification of human remains. 2nd edition. Springfield, IL. 333–52.

Berryman HE, Lanfear AK, Shirley NR. 2012. The biomechanics of gunshot trauma: research considerations within the present judicial climate. In: D Dirkmaat, ed. A companion to forensic anthropology. 1st edition. Blackwell Publishing Ltd.

Bir C, Andrecovich C, DeMaio M, Dougherty PJ. 2016. Evaluation of bone surrogates for indirect and direct ballistic fractures. Forensic Sci Int 261:1–7.

Byers SN. 2015. Introduction to forensic anthropology: Routledge.

Chapman KA. 2007. When the Bullet Hits the Bone: Patterns in Gunshot Trauma to the

Infracranial Skeleton. San Marcos: Texas State University.
Clasper J. 2001. The interaction of projectiles with tissues and the management of ballistic fractures. J R Army Med Corps 147(1):52–61.
de la Grandmaison GL, Clairand I, Durigon M. 2001. Organ weight in 684 adult autopsies: new tables for a Caucasoid population. Forensic Sci Int 119(2):149–54.
DiMaio V. 2015. Gunshot wounds: practical aspects of firearms, ballistics, and forensic techniques. Baca Raton, FL: CRC Press: Taylor & Francis Group.
Dirkmaat D. 2014. A companion to forensic anthropology: John Wiley & Sons.
Fackler M. 1987. Whats wrong with the wound ballistics literature, and why. DTIC Document.
Fackler M. 1988. Would ballistics. A review of common misconceptions. JAMA 259(18):2730–36.
Hamblen DL, Simpson AHR, Adams JC. 2007. Adams's outline of fractures, including joint injuries: Elsevier Health Sciences.
Harger JH, and Huelke DF. 1970. Femoral fractures produced by projectiles—the effects of mass and diameter on target damage. J Biomech 3(5):487–93.
Harvey EN, McMillen J, Butler E, Puckett W. 1962. Mechanism of wounding. Wound ballistics Ed JB Coates and JC Beyer Office of the Surgeon General, Medical Department of the US Army, Washington, USA:144–235.
Hollerman J, Fackler M, Coldwell D, Ben-Menachem Y. 1990. Gunshot wounds: 1. Bullets, ballistics, and mechanisms of injury. Am J Roentgenol 155(4):685–90.
Huelke DF, Harger J, Buege L, Dingman H, Harger D. 1968. An experimental study in bio-ballistics: Femoral fractures produced by projectiles. J Biomech 1(2):97–105.
Humphrey C, Kumaratilake J. 2016. Ballistics and anatomical modelling – a review. Leg Med 23:21–29.
Humphrey C, Henneberg M, Wachsberger C, Maiden N, Kumaratilake J. 2017. Effects of re-heating tissue samples to core body temperature on high velocity ballistic projectile–tissue interactions. J Forensic Sci. doi: 10.1111/1556-4029.13473.
Janzon B. 1983. High energy missile trauma: a study of the mechanisms of wounding of muscle tissue. University of Gothenburg.
Janzon B, Hull J, Ryan J. 1997. Projectile-material interactions: soft tissue and bone. In: GJ Cooper, HA Dudley, DS Gann, RA Little, and RL Maynard, eds. Scientific foundations of trauma. Oxford: Butterworth-Heinemann. 37–52.
Jönsson A, Arvebo E, Schantz B. 1988. Intrathoracic pressure variations in an anthropomorphic dummy exposed to air blast, blunt impact, and missiles. J Trauma Acute Care Surg 28(1):S125-S131.
Kieser DC, Riddell R, Kieser JA, Theis J-C, Swain MV. 2014. Bone micro-fracture observations from direct impact of slow velocity projectiles. J Arch Mil Med 2(1):e15614.
Lahren CH, Berryman HE, O'Brian CS. 1987. Cranial fracture patterns and estimate of direction from low velocity gunshot wounds. J Forensic Sci 32(5):1416–21.
Langley N. 2007. An anthropological analysis of gunshot wounds to the chest. J Forensic Sci 52(3):532–7.
Mabbott A, Carr DJ, Champion S, and Malbon C. 2016. Comparison of porcine thorax to gelatine blocks for wound ballistics studies. Int J Legal Med 130(5):1353–62.
Mellor S. 1994. Characteristics of missile injuries. In: JL Williams, ed. Rowe and Williams' maxillofacial injuries. 2nd edition. Edinburgh: Churchill Livingstone. 666–74.
Molde Á, Gray R. 1995. High-velocity gunshot wound through bone with low energy transfer. Injury 26(2):131.
Quatrehomme G, İşcan MY. 1997. Bevelling in exit gunshot wounds in bones. Forensic Sci Int 89:93–101.
Quatrehomme G, and İşcan MY. 1998a. Analysis of beveling in gunshot entrance wounds. Forensic Sci Int 93:45–60.

Quatrehomme G, İşcan MY. 1998b. Gunshot wounds to the skull: comparison of entries and exits. Forensic Sci Int 94:141–46.

Quatrehomme G, İşcan MY. 1999. Characteristics of gunshot wounds in the skull. J Forensic Sci 44(3):568–76.

Robens W, Küsswetter W. 1982. Fracture typing to human bone by assault missile trauma. Acta Chir Scand Suppl 508:223–27.

Rothschild M. 2011. Conventional forensic medicine. Wound ballistics: basics and applications. Berlin: Springer-Verlag.

Schantz B. 1978. Aspects on the choice of experimental animals when reproducing missile trauma. Acta Chir Scand Suppl 489:121–30.

Sellier K, Kneubuehl B. 1995. Wound ballistics and the scientific background. Am J Forensic Med Pathol 16(4):355.

Smith HW, Wheatley KK. 1984. Biomechanics of femur fractures secondary to gunshot wounds. J Trauma Acute Care Surg 24(11):970–77.

Spitz WU, Spitz DJ. 2006. Spitz and Fisher's medicolegal investigation of death: guidelines for the application of pathology to crime investigation. Spingfield, IL: Charles C. Thomas.

Stefanopoulos PK, Soupiou OT, Pazarakiotis VC, Filippakis K. 2015. Wound ballistics of firearm-related injuries-Part 2: Mechanisms of skeletal injury and characteristics of maxillofacial ballistic trauma. Int J Oral Maxillofac Surg 44(1):67–78.

Symes SA, L'Abbé E.N, Chapman E.N, Wolff I, Dirkmaat DC. 2012. Interpretating traumatic injury to bone in mediocolegal investigations. In: Dirkmaat DC, ed. A companion to forensic anthropology. Chichester, UK: John Wilen & Sons. 340–89.

Tersigni-Tarrant MA, Shirley NR. 2012. Forensic anthropology: an introduction. CRC Press.

Ubelaker D. 1995. The remains of Dr. Carl Austin Weiss: Anthropological analysis. J Forensic Sci 41(1):60–79.

Viel G, Gehl A, Sperhake JP. 2009. Intersecting fractures of the skull and gunshot wounds. Case report and literature review. Forensic Sci Med Pathol 5(1):22–27.