J Forensic Sci, May 2007, Vol. 52, No. 3
doi:10.1111/j.1556-4029.2007.00413.x
Available online at: www.blackwell-synergy.com

Natalie R. Langley,[1] *M.A.*

An Anthropological Analysis of Gunshot Wounds to the Chest*

ABSTRACT: This analysis of gunshot trauma to the bony thorax examines 87 handgun and rifle wounds from documented cases in an effort to corroborate an earlier report and to provide the forensic community with additional literature in this area. Specifically, this study tests whether the trauma signatures associated with gunshot wounds in the bony thorax are useful in determining the direction of fire. Because the ribs occupy a significant portion of the bony thorax, they are struck more frequently than other bones and, consequently, they are the focus of this report. This study confirmed that bullets can leave distinctive markers on ribs that indicate the direction of fire, including depressed fractures, bone fragments displaced in the direction of the bullet's path, and beveling. Although forensic anthropologists can determine the direction that a bullet was traveling when it struck a given rib, they cannot give a *definitive* statement about the number or sequence of gunshots without supporting soft tissue evidence.

KEYWORDS: forensic science, forensic anthropology, gunshot wounds, high-velocity trauma, skeletal trauma, thorax

The increasing use of firearms and the corresponding rise in gunshot fatalities have put wound ballistics on the top priority list in medical and forensic research. In 2004, firearms were used in 26.4% of violent crimes in the United States (e.g., aggravated assault, robbery, and murder offenses) (1). Of these offenses, 70% of homicides were committed with firearms, 78% of which were handguns (1). Consequently, researchers have published an abundance of literature on the subject within the past 50 years, and we now have a good understanding of a bullet's behavior upon entering the body. Much of the literature on wound ballistics concentrates on soft tissue damage. The majority of the literature on bone damage concentrates solely on the skull, however. The focus of this study is gunshot trauma to the bony thorax—an area for which a paucity of published literature exists.

To date, the most detailed descriptions of gunshot wounds to the bony thorax were reported by Douglas Ubelaker in his anthropological analysis of the exhumed remains of Dr. Carl Austin Weiss (2). In 1935, Dr. Weiss was shot while allegedly attempting to assassinate Governor Huey P. Long of Louisiana. Both men died, but no autopsy was performed on either body. In 1991, Dr. Weiss' remains were exhumed in an attempt to corroborate the physical evidence with the historical record. Ubelaker found that at least 20 bullets penetrated Dr. Weiss' body, and the majority of these projectiles penetrated the chest. In this case report, Ubelaker pays particular attention to evidence for directionality. Ubelaker noted several factors that provide evidence for direction of fire, including displaced bone fragments, depressed fractures, beveling, and overall fracture patterns. Using these indicators, Ubelaker was able to conclude that most of the bullets traveled through Dr. Weiss' chest from posterior to anterior.

The present analysis of gunshot trauma to the bony thorax uses cases documented by the medical examiner to investigate projectile trauma in a contemporary setting. This study focuses on trauma signatures caused by gunshot wounds to the thoracic region and assesses the usefulness of these features in determining the direction of fire. Although no research is decisive and without error, the information in this summary contributes to the existing database on skeletal trauma and underscores areas where further research would be useful.

Materials and Methods

Fifty-three documented cases with gunshot wounds to the thorax were selected for analysis from the evidentiary archives at the Regional Forensic Center in Memphis, Tennessee. The evidentiary archives in the forensic anthropology laboratory are organized by case number and are labeled with the retained skeletal elements and type of trauma (i.e., blunt, knife stab wound, gunshot wound, shotgun wound, etc.). Only injured bones and, in many cases, immediately neighboring bones are retained for evidentiary purposes. Additionally, one case was examined from the Louisiana State University forensic anthropology laboratory, thus making a total of 54 cases. Some of these individuals had received only a single gunshot wound to the chest, while others had multiple gunshot wounds. In sum, 87 gunshot wounds to the thoracic region were included in this sample. The criteria for inclusion were cases with handgun or rifle wounds to the thoracic region. Shotgun wounds were omitted from this analysis because of the unique wounding properties of these firearms.

Bone damage and direction of fire were assessed through visual examination. An operating scope with $6\times$ to $40\times$ magnification capabilities was used to view fractures more closely, particularly in cases in which the origin of the fracture was not evident to the naked eye. In addition, autopsy records were reviewed in order to compare the anthropological assessment with the pathologist's evaluation. The caliber of the bullet was noted when this information was present in the autopsy protocol, although no attempt was made to correlate bullet caliber to wound dimensions.

[1]University of Tennessee, Department of Anthropology, 250 South Stadium Hall, Knoxville, TN 37996.

*Presented orally at the 2002 AAFS Annual Meetings in Atlanta, GA.

Received 15 April 2006; and in revised form 28 Oct. 2006; accepted 5 Nov. 2006; published 5 April 2007.

Results

Of the 87 gunshot wounds examined in this study, 41% injured only one bone, 37% involved two bones, 6% involved three bones, and 2% injured more than three bones; 14% of the gunshot wounds did not strike any bones. The two cases that involved more than three bones were rifle wounds. In all, 134 injured bones were examined: six clavicles, five scapulae, 11 sterna, 11 vertebrae, and 101 ribs. Before describing the wounds observed in the ribs, the characteristics of the defects in the other bony elements will be discussed briefly.

Clavicle

Because of its tubular shape and high ratio of cortical bone to trabecular bone, the clavicle fractured in a manner similar to a long bone when struck by a bullet. Long bone shafts typically "explode" in the same manner as the soft tissues around them (3–6). The result is a severely shattered bone that, when reconstructed, reveals a clearly demarcated entrance wound with internal beveling, but no corresponding exit wound. The absence of a noticeably defined exit wound could be attributed to the fact that fracture lines caused by the bullet's entrance propagate faster than the bullet travels. Thus, the fracture lines comminute the bone shaft before the bullet has a chance to form a clean exit wound. Five of the six clavicles examined in this study were fractured in half at the site of impact; the sixth was only grazed by a bullet as it entered the first rib. After reconstruction, the entrance wound was visible as a circular hole with clean, sharp edges, but there was no clearly delineated exit wound. However, bone fragments were displaced in the direction of the bullet's trajectory in half of the cases, which indicated the direction of fire (Fig. 1).

Vertebrae

Figure 2 shows the typical vertebral trauma observed in this study. Five of the 10 thoracic vertebrae were shattered beyond reconstruction. The remaining five had incomplete fractures to the transverse processes, spinous process, and/or body. The vertebral injuries were caused by a bullet striking the vertebra directly, by a bullet striking the rib at its articulation with the vertebra, or by a combination of these two scenarios. The injury to the lumbar vertebra was a graze wound, which made a depressed fracture on the lateral aspect of the body. Overall, the direction of fire could not be determined from the appearance of the vertebral trauma due to the massive fragmentation of the vertebrae in these cases.

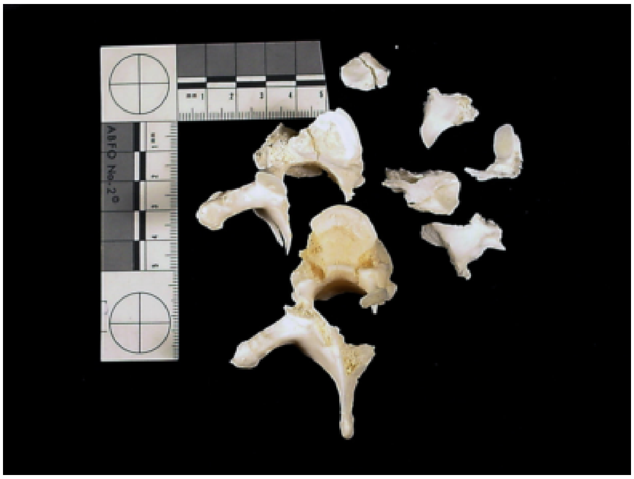

FIG. 2—*Thoracic vertebrae 3, 4, and 5. Bullet entered intercostal space 1–2 and fractured the vertebrae upon exit.*

FIG. 1—*Gunshot wound in right clavicle (reconstructed). Bone was fractured into two pieces. Note the bone fragment displaced in the direction of fire at the exit site. 0.38 caliber bullet did not exit the body.*

Sternum

The bullet's path through the bone was more evident on the sternum. The entrance wound was usually a circular hole with sharp edges. Occasionally, depressed fractures were present on the outer rim of the circular hole (Fig. 3). In instances in which the bullet did not possess enough energy to perforate the bone, the entrance defect was a round indentation in the bone comprised of one or more depressed fractures. Typical beveling was present around the exit site and, frequently, bone fragments were displaced in the direction that the bullet traveled through the sternum (Fig. 4).

Scapula

The scapula is an irregular bone in terms of its shape and lack of uniform thickness. Nonetheless, displaced bone fragments and/or depressed fractures proved to be useful indicators of the direction

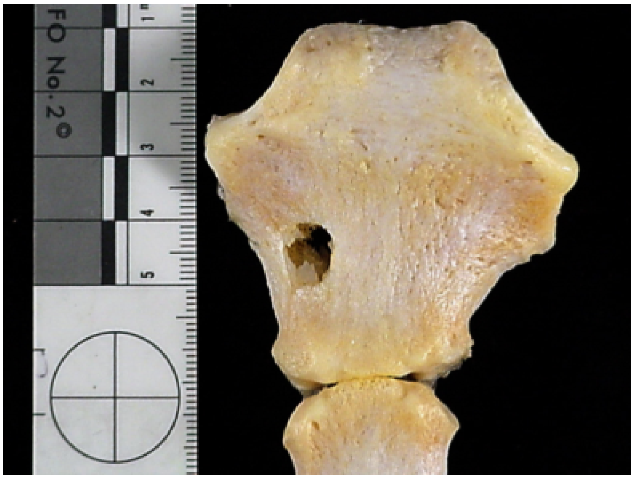

FIG. 3—*Entrance defect on ventral manubrium. Note the depressed bone fragments on the inferior and lateral margins.*

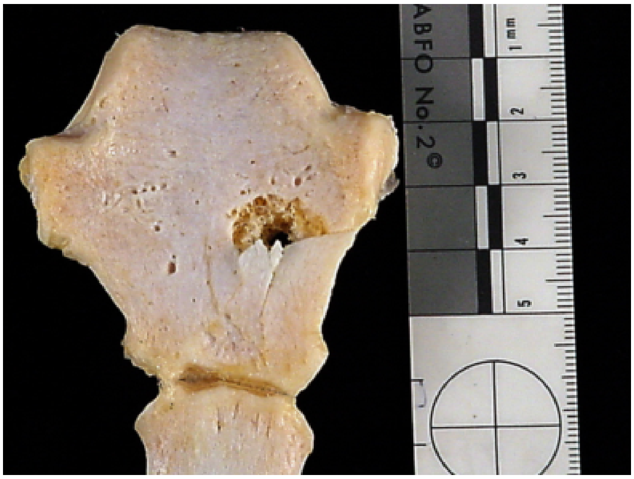

FIG. 4—*Exit defect on manubrium. Note beveling around the exit defect and bone fragment displaced in the direction of the bullet's path.*

of fire (Fig. 5). However, these observations were based on only five scapulae. A larger sample is necessary to make accurate conclusions about the wounding response of the scapula, clavicle, sternum, and vertebrae.

Ribs

The ribs were the most frequently injured bones in this sample (75% of the total sample). The bilateral distribution of the rib injuries was almost even, with 54% on the right side and 46% on the left side. Not unexpectedly, the center of the rib cage was injured more frequently than the upper and lower portions. Table 1 presents a summary of the characteristic features of entrance and exit defects in ribs.

Several reoccurring features in gunshot wounds in the ribs served as useful indicators of the direction of fire. The entrance defect is typically a circular, ovoid, or semicircular hole with a sharply defined rim and no beveling. The shape of the defect depends on the orientation of the bullet as it strikes the rib and on the area of the rib that it strikes. For example, a bullet that grazes the superior or inferior aspect of a rib will usually leave a semicircular defect because only part of the bullet actually makes contact with the rib (Fig. 6). A bullet that penetrates the rib at midshaft either will leave a circular hole in the rib, or it will fracture the rib completely in half. In the latter situation, a round defect with clean edges is usually visible after reconstruction of the bone fragments. In one case, the bullet struck the rib in a sideways orientation, and the shape of the defect reflected this entry angle (Fig. 7). Additionally, entrance defects may be surrounded by radiating fracture lines and/or by depressed fractures (Fig. 8). Depressed fractures are particularly good indicators of the direction of fire because they are displaced in the direction of the bullet's path.

TABLE 1—*Characteristics of the entrance and exit defects in ribs.**

Entrance	Exit
Typically round defect	Larger, more irregular-shaped defect
Sharp margins	Beveling
Radiating fractures	Radiating fractures
Depressed fractures	Displaced bone fragments

*One or more of these features may be present. All are useful in determining the direction of fire.

An exit defect on a rib is typically larger than the corresponding entrance defect, unless the bullet barely grazes the rib or reaches terminal velocity as it strikes the rib (Fig. 9). As with exit defects in the cranial vault, trabecular bone is visible in the area immediately surrounding the exit defect (i.e., beveling). However, due to the architecture and intrinsic properties of the ribs and chest cavity, the beveling takes on a different shape than it does in typical cranial exit wounds. Frequently, the exit defects in ribs are ovoid in shape, as opposed to the more circular defects seen in the cranial vault (Fig. 10). Also, bone splinters may be displaced in the direction in which the bullet was traveling (Fig. 11). As with entrance defects, radiating fracture lines may surround the exit defect.

Discussion

It is possible to determine the direction that a bullet traveled through a given rib. However, interpretations from the bony thorax alone cannot specify with certainty the number or sequence of gunshot wounds without supporting ballistic and/or soft tissue

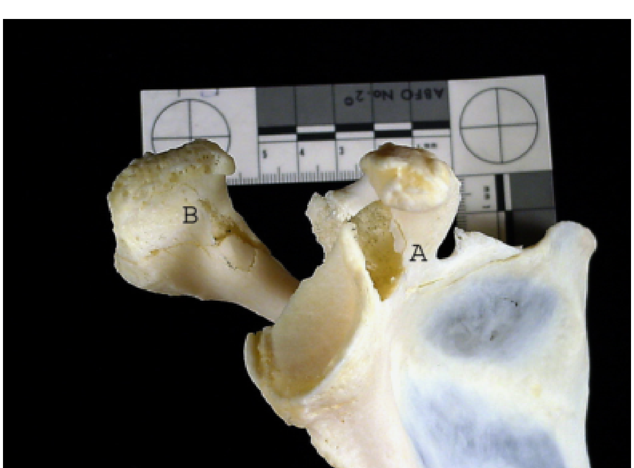

FIG. 5—*Gunshot wounds in right scapula. The bullet traveled through the coracoid process (A) and terminated at the acromion (B). Note the depressed fractures on both defects.*

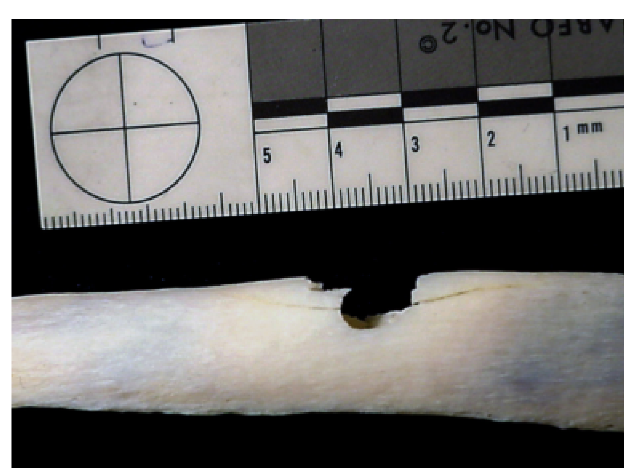

FIG. 6—*Entrance defect on left rib 7. A 0.25 caliber Automatic Colt Pistol bullet clipped the superior margin of the rib. Note the radiating fracture lines extending from each side of the defect.*

FIG. 7—*Entrance defect on the ventral surface of left rib 7 (vertebral end). The ovoid shape indicates that the full metal-jacketed bullet struck the rib in a sideways orientation.*

FIG. 9—*A 0.22 caliber long rifle bullet clipped the inferior margin of left rib 3 as it exited the body. The bullet nicked the bone (arrow) and a displaced fragment of bone in the direction of fire.*

evidence. The autopsy reports from this study indicated that *c.* 20% of the bullets in this sample traveled through intercostal spaces without leaving evidence on the bone. Nonetheless, the forensic anthropologist's skeletal analysis can provide additional support to the pathologist's report that can be used in the court of law.

This study corroborates Ubelaker's observations that gunshot wounds in the chest can leave evidence on the bones indicating the direction of fire (2). Owing to the large surface area that the ribs occupy in the thoracic region, they are the bony elements injured most frequently in gunshot wounds to the chest. Several characteristics that are useful in evaluating gunshot wounds in ribs are depressed fractures, bone fragments displaced in the direction of the bullet's path, and beveling (2). The best way to determine which of these characteristics is present at the site of trauma is to examine the defect closely under a microscope.

Some authors categorize ballistic bone trauma according to the type of bone involved (i.e., long bones vs. flat bones) (4,5). Long bones are the tubular bones of the limbs, and flat bones are the bones of the cranial vault and the ribs. Bullets produce distinctive wounds in each type of bone due to the macroscopic and microscopic structural differences between long and flat bones (i.e., shape, amount of cortical bone, amount of trabecular bone) (3–6). As discussed previously, bullet injuries in long bone shafts typically have a clearly demarcated entrance wound with no corresponding exit wound. Flat bones, on the other hand, usually have clearly demarcated entrance *and/or* exit wounds. The trademark of gunshot wounds in the cranium is beveling, specifically internal beveling associated with the entrance site and external beveling associated with the exit site. Additionally, radiating and concentric heaving fractures may be present (7–9). Symes et al. (8) contend that this characteristic beveling is the result of "spalling," which occurs as a result of the interaction of tensile and compressive forces on the internal and external skull tables.

Certainly tensile and compressive forces are acting on the ribs as well, but the intrinsic properties of the ribs differ from those of the cranial bones, even though they are both categorized as flat bones. Bone fractures are influenced by intrinsic and extrinsic factors (7). Intrinsic factors include the density, stiffness, and fatigue strength of bone. Extrinsic factors include the direction, magnitude, duration, and rate of the force applied to bone. Bone is a viscoelastic material in that it can behave as a ductile or brittle

FIG. 8—*Entrance defect on right rib 5 showing sharp margins and multiple radiating fracture lines.*

FIG. 10—*Exit defect on right rib 5 (same gunshot wound as Fig. 8). Note the ovoid shape of the beveled area. The entrance defect on the opposite surface of the rib is visible through the exit defect.*

FIG. 11—*Superior view of the gunshot wound in Fig. 9 showing the displaced fragment of bone at the exit site.*

material depending on the force delivered to it (i.e., the velocity, rate, and duration of the force) (7,10). Ductile materials can absorb more energy before failure than brittle materials. For example, osteoporotic bone is more brittle than young, healthy bone. In the case of gunshot trauma, bone typically behaves as a brittle material unless the bullet has lost most of its energy before impacting the bone.

One difference between the flat bones of the ribs and those of the cranial vault is the density of the trabecular bone. Cranial bones have a dense layer of trabecular bone between the inner and outer tables; this layer is less dense in the ribs. In addition, the cortical layers are more compact in the vault than in the ribs. Another difference is that the cranial vault is a more rigid structure than the rib cage, which must allow for movements associated with inspiration and exhalation. Consequently, less pressure build-up occurs when a bullet enters the chest cavity than when a bullet enters the cranial vault.

These contrasts between the intrinsic properties of the bony thorax and cranial vault create different injury mechanics in these two areas of the body. These differences are apparent in some characteristics of gunshot wounds in the ribs versus the cranial vault. For example, the shape of the externally beveled area in the ribs is ovoid, whereas it is round in the vault. Another difference is the absence of concentric heaving fractures in ribs. These fractures are absent because the air-filled lungs do not allow for significant cavity formation; consequently, there is insufficient pressure build-up to produce such fractures (4). Another distinction is that depressed fractures at the entrance site and displaced bone splinters at the exit site occur more frequently in the ribs than in the cranial vault. The bony thorax's capacity to absorb more energy before bursting than the cranial vault may account for the prevalence of these features in rib wounds. One would only expect such features in the vault in situations in which the bone plastically deforms (i.e., behaves more like a ductile material than a brittle material, such as in some instances of blunt trauma).

Clearly, then, the complex interaction of extrinsic and intrinsic factors influences fracture production, and a good understanding of these variables is imperative to comprehensive trauma analysis (7). Categorizing trauma according to bone type (i.e., long bone vs. flat bone) may be too simplistic. Rather, careful consideration of the intrinsic and extrinsic factors at play in any traumatic event may be more useful in characterizing trauma signatures in bone.

Owing to the numerous variables that contribute to wound formation, no attempt was made to correlate the dimensions of the wound to bullet caliber. Several factors influencing the appearance of gunshot wounds are the velocity of the bullet at the point of entrance, the distance between the muzzle and the target, the position of the body at the time of impact, the angle of entry, and the presence or absence of clothing (3). Additionally, bullet caliber, shape, surface treatment, strength characteristics, tangential impacts, and intermediate targets contribute to the appearance of gunshot wounds (11). Symes et al. (8) warn that, while consistencies can exist under controlled conditions, it is not advisable to predict bullet caliber in a clinical case, particularly because bullets can leave holes in bones that are smaller in diameter than the bullet once the wound tract settles into its final configuration. While some authors have been able to distinguish between small- and large-caliber bullets in the cranium, they concede that there is an area of overlap and recommend exercising caution when attempting to estimate bullet caliber from wound dimensions (11,12).

A number of authors suggest that fractures can occur some distance from the wound tract, particularly in the case of high-powered rifles (3,6,13–15). These authors propose that excessive pressure build-up in the tissues surrounding the wound tract causes these indirect fractures. Owing to the extremely high velocity of rifle projectiles (sometimes in excess of 900 m/sec), an enormous amount of kinetic energy can be transferred to the body tissues and potentially cause fractures beyond the wound tract. None of the cases in this study had secondary fractures, regardless of the velocity or caliber of the projectile. However, only two of the cases involved high-powered rifles.

One explanation as to why rib fractures were not found beyond the wound tract concerns the nature of lung tissue. The lungs have a low water content, low specific gravity, and high elasticity; consequently, they can absorb high levels of kinetic energy without bursting (16,17). This absorbing capability could serve to protect ribs that may otherwise fracture. Secondary fractures may occur in other areas of the body, but the lungs likely reduce the chances of this occuring in the chest cavity (4). Although a statistically valid assumption cannot be made with only two documented rifle cases, this researcher felt that the findings in this study regarding secondary fracture occurrence warranted mention.

Additionally, this study has brought forth questions that warrant further research. For example, can the *precise angle* of entry (i.e., trajectory) be determined for gunshot wounds in ribs? Spitz (18) suggests that the asymmetry of beveling may be useful in determining the bullet's trajectory. Additional information that may be useful in addressing this question includes the dimensions of the entrance and exit defects, the relationship between the location of the entrance defect and the corresponding exit defect, and the nature and location of features such as depressed fractures and displaced bone fragments.

As indicated earlier, analysis of a larger sample of scapulae, clavicles, vertebrae, and sterna may reveal significant details that were not addressed in this study. Experimental studies using human cadavers, controlled impacts, and flash photography have proved valuable in understanding blunt trauma biomechanics (19). Extending these methods to ballistic studies certainly would provide a deeper insight into the mechanics of ballistic bone trauma.

Acknowledgments

I would like to thank the entire staff at the Regional Forensic Center in Memphis, TN, for permission to use the evidentiary archives and for their friendliness and helpfulness during my stay. Special thanks are due to Dr. Steven A. Symes. Dr. Symes not only helped me gain a better understanding of skeletal trauma, but he has guided me in my academic pursuits as well. I would also like to thank Mary H. Manhein for access to the Louisiana State University collection and for her support as my thesis committee chair. Finally, I thank Dr. Heather McKillop for her comments on my thesis. Funded by a research grant from the Robert C. West Fund from the Louisiana State University Department of Geography and Anthropology.

References

1. http://www.fbi.gov/ucr/cius_04/index.html
2. Ubelaker DH. The remains of Dr. Carl Austin Weiss: an anthropological analysis. J Forensic Sci 1996;41(1):60–79.
3. DiMaio VJ. Gunshot wounds: practical aspects of firearms, ballistics, and forensic techniques. 2nd revised ed. New York: Elsevier Science Publishing Company, 1993.
4. Coates J, Beyer J, editors. Wound ballistics. Washington, DC: Office of the Surgeon General, Department of the Army, 1962.
5. Harvey FM, Jones AM. "Typical" basal skull fracture of both petrous bones: an unreliable indicator of head impact site. J Forensic Sci 1980; 25(2):280–6.
6. Welti C, Mittleman R, Rao V. An atlas of forensic pathology. Chicago: American Society of Clinical Pathologies, 1999.
7. Berryman HE, Symes S. Recognizing gunshot and blunt cranial trauma through fracture interpretation. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield: Charles C. Thomas, 1998:333–52.
8. Symes SA, Smith OC, Berryman H, Peters C, Rockhold L, Huan S et al. Bones: bullets, burns, bludgeons, blunders, and why. Proceedings of the 48th Annual Meeting of the American Academy of Forensic Sciences; February 19–24 1996. Nashville, TN, Colorado Springs, CO: American Academy of Forensic Sciences, 1996:10–1.
9. Smith OC, Berryman HE, Lahren CH. Cranial fracture patterns and estimate of direction from low velocity gunshot wounds. J Forensic Sci 1987; 32(5):1416–21.
10. Smith OC, Berryman HE, Symes SA, Francisco JT, Hnilica V. Atypical gunshot exit defects to the cranial vault. J Forensic Sci 1993;38(2):339–43.
11. Berryman HE, Smith OC, Symes SA. Diameter of cranial gunshot wounds as a function of bullet caliber. J Forensic Sci 1995;40(5):751–4.
12. Ross AH. Caliber estimation from cranial entrance defect measurements. J Forensic Sci 1996;41(4):629–33.
13. Adelson L. The pathology of homicide. Springfield: Charles C. Thomas, 1974.
14. Berlin R, Janzon B, Kokinakis W, Eiseman B, Albrecht M, Owen-Smith M, et al. Various technical parameters influencing wound production: a panel discussion. Acta Chirurgica Scandinavica 1979;489(Suppl):103–20.
15. Morse D. The skeletal pathology of trauma. In: Morse D, Duncan J, Stoutamire J, editors. Handbook of forensic archaeology and anthropology. Tallahassee: Florida State University Foundation, 1984:145–56.
16. Amato JJ, Billy LJ, Lawson NS, Rich NM. High velocity missile injury: an experimental study of the retentive forces of tissue. Am J Surgery 1974; 127:454–9.
17. DeMuth W. High velocity bullet wounds of the thorax. Am J Surgery 1968;115:616–25.
18. Spitz W. Gunshot wounds. In: Spitz W, Fisher R, editors. Medicolegal investigation of death: guidelines for the application of pathology to crime investigation. Springfield: Charles C. Thomas, 1980:216–75.
19. Kroman A, Symes SA, Kress TA. Fracture propagation in the human cranium: a re-testing of popular theories. J Forensic Sci, in press.

Additional information and reprint requests:
Natalie R. Langley, M.A.
Department of Anthropology
University of Tennessee
250 South Stadium Hall
Knoxville, TN 37996
E-mail: nlangley@utk.edu