TECHNICAL NOTE

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Cranial Fracture Patterns and Estimate of Direction from Low Velocity Gunshot Wounds

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ABSTRACT: Cranial trauma produced by low velocity gunshot wounds is investigated in an autopsy series. In skeletonized remains with postmortem damage, or after surgical debridement, the primary internal or external beveling may become obscured, causing difficulty with the identification of entrance and exit wounds. The morphology of associated secondary and tertiary fractures based upon the mechanics of their production is discussed as a means of establishing bullet entrance and exit sites.

KEYWORDS: pathology and biology, wound ballistics, ballistics, musculoskeletal system

Through-and-through gunshot wounds of the head may be difficult to interpret for several reasons. Animal, environmental, or collection damage to decomposed remains, surgical debridement of bone, and atypical entrance wounds as described by Coe [*1*] and Dixon [*2,3*] may create confusion. A review of the medical literature produces descriptive case reports, but little information on the biomechanics involved. However, much information is available on the fracture characteristics of brittle materials which can be applied to somewhat more viscoelastic substances like bone. A cogent application of the biomechanics of secondary and tertiary fracture patterns, independent of entrance or exit beveling, can determine the direction a bullet has taken through the head.

Materials and Methods

Calvaria containing through-and-through low velocity wounds of known direction were obtained at autopsy. Ten were processed to remove the soft tissue and the fracture patterns were observed and correlated. Once the process of fracture production was understood, subsequent specimens were studied in the fresh state.

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Results and Discussion

Considering the internally beveled entrance wound (consisting of the plug and spall) to be the primary fracture, a sequence of secondary and tertiary fractures of two consistent types were noted. The first type to form will be radial fractures originating from the point of bullet impact. Next, and less common, are concentric heaving fractures occurring as a tertiary event, following the production of the secondary radial fractures. Concentric heaving fractures appear as a series of arcs or generations of circular fractures centered about the point of impact (but not related to the primary spalling effect) and connect the radial fracture lines.

Radial fractures represent release of circumferential hoop stresses induced by the bullet's impact [*4*]. Frequently, radial fractures alone appear to be sufficient to relieve the stresses and concentric heaving fractures are not formed. Our observations indicate that while radial fractures may be found alone, concentric heaving fractures are never observed without the presence of radial fractures. This leads one to believe that radial fractures form first and quite rapidly, to be followed by the concentric heaving fractures if additional stress relief is required [*4,5*]. Observations supporting this statement include the fact that stress crack propagation of brittle materials occurs at high velocity [*4*]. Also, Gonzales et al. [*6*] reported a bullet exiting through one margin of a radial fracture that had been sufficiently distracted so as not to strike the opposing margin. Further, in agreement with Dixon [*7*] is our observation that propagation of later fractures are arrested as they cross preexistent fracture lines. This means the circular appearance of the concentric heaving fractures is in reality a series of independent arcs between the radial fractures, sharing similar radii.

Examining cross sections of radial fractures (Fig. 1*d*) reveals them to be either perpendicular to the whole thickness of the skull or stair-step in configuration with the horizontal component located in the diploë. These findings are consistent with hoop stress tension fractures of brittle materials where the fracture line is perpendicular to the axis of tension [*4*].

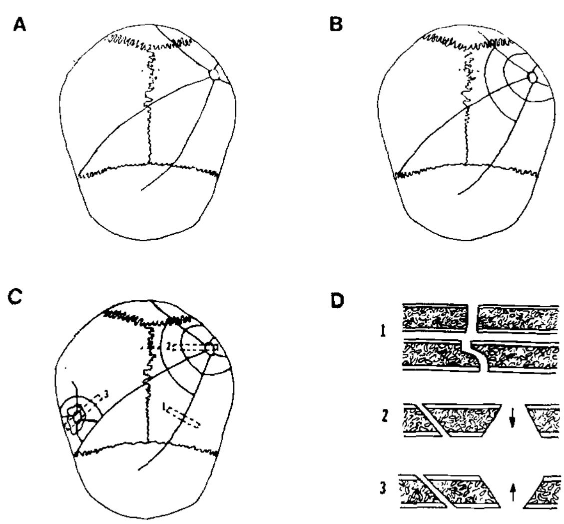

FIG. 1—*These diagrams show the sequence of fracture production. A bullet entering the skull produces an entrance wound and a series of radial fractures extending across the skull in advance of the bullet to relieve hoop stresses* (a). *Concentric heaving fractures develop in successive generations connecting the radial fractures as the wedges are lifted up* (b). *Upon exit there is another series of radial and concentric heaving fractures produced that are of lesser magnitude, have fewer generations, and may be arrested by preexistent fracture lines* (c).

The stair-step appearance probably results from shear forces across trabeculae in the diploë generated when fractures in the tables are not perfectly aligned. Radial fractures are seldom extensively beveled, a feature more consistently noted with concentric heaving fractures. When this does occur, however, the beveling tends to wander from one side to the other. A rough positive correlation was noted between the length or magnitude of the radial fractures and the relative power of the weapon.

The concentric heaving fracture is so named because the margins are typically beveled, indicating that it is caused by an upward levering of the fractured skull plates. We feel the mechanism is a result of increased intracranial pressure. We do not feel that secondary transition phenomena or stress wave propagation are sufficient to cause these concentric fractures. First, the fractures do not indicate a direction of force coinciding with the bullet flight (as beveled entrance and exit wounds do). Second, the primary and radial fractures are known to occur before the concentric fracture with much relief of bullet impact stress. Stress wave propagation fractures should appear at about the same time as the first two but are not seen. Third, while brittle materials react predictably, the viscoelasticity of living bone serves to reduce the tendency of secondary transition phenomena to result in observable fractures. Finally, beveling of the concentric fractures indicates the forces originate inside the calvarium for both entrance and exit defects.

Examination of the beveling (Fig. 1*d*) is consistent with an inner table tension fracture propagating outward and distal to the original moment arm. Since bone's tensile strength is less than its compressive strength [*8*], tension in the inner table, and compression of the outer table, results in the fracture of the inner table first. The logical direction of this force has to be outward, away from the head causing the wedge of bone between the bordering radial fractures to be levered up and out. This is exactly the opposite of Moritz's observations [*9*] but not inconsistent with his principles. He was writing of large, forceful blunt objects striking from the outside, so his concentric beveling is reversed from ours, indicating a compressive force. However, his principles are preserved when an expansive fracturing force originates within the skull. The beveling produced is not necessarily constant, however, when a particularly curved portion of the skull is involved, the curvature appears to cancel out the beveling action, producing a relatively perpendicular fracture. At no time was a reverse bevel noted.

The concentric heaving fractures cannot propagate beyond the preexistent radial fractures, but appear to because of their similar radii. This probably reflects the similar magnitude of stresses developed in the wedges and their similar resistance to fractures. Multiple generations of concentric heaving fractures of increasing radii are noted when more powerful weapons are used.

Exit wounds exhibit similar fracture patterns as a result of release of the same forces caused by bullet impact and increased intracranial pressure. However, exit fractures differ from entrance fractures in several significant ways. First, they are of lesser magnitude than those associated with entrance wounds. Radial fractures are not as long and concentric heaving fractures show smaller radii and fewer generations. This is to be expected as the bullet has already expended much of its energy before exiting, and displacement of fragments in the now fractured skull may partially relieve the exit stresses. Second, because of the preceeding entrance fractures, exit fractures are more likely to be arrested. Gonzales et al. [*6*] have shown that entrance fractures propagate across the skull faster than the bullet passes through the brain. These relationships provide the basis needed to establish bullet direction in the absence of beveled entrance and exit wounds. Third, when these primary bevels are available, the entrance bevel and its concentric heaving bevel are opposed to each other, while at the exit site, these bevels are roughly parallel (Fig. 1*d*). This lends support to our theory that concentric heaving bevels are due to intracranial overpressure as opposed to secondary transition phenomena (reflected tensile waves or elastic wave phenomena). If secondary phenomena were responsible for heaving fractures, then they should indicate bullet direction since they must align with the direction of force along the line of bullet travel [*4,5*]. Primary fractures certainly reflect this directionality of bullet impact, heaving fractures do not. Heaving fractures indicate only an outward force vector regardless of bullet direction (in or out). This explains why the heaving fracture bevel does not show the direction. Further, it may be concluded that secondary transition phenomena are limited to the primary fracture where their pattern is consistent with the direction of impact.

The sequence of drawings in Fig. 1*a-c* depicts the serial mechanism postulated for a skull being fractured by a bullet coursing through the head. Figure 1*a* shows the entrance wound and the rapid development of radial fractures. As rapid release of hoop stresses along these radial cracks causes them to separate, they propagate to the opposite side of the skull in advance of the bullet. As the intracranial pressures build, the bony wedges begin to heave up, producing arc-like fractures of similar radii and several generations (Fig. 1*b*). Finally, upon exiting, the bullet causes additional radial and concentric heaving fractures which are less extensive, have shorter radii with fewer generations, and may be arrested when they cross preexistent entrance associated fractures (Fig. 1*c*).

Figures 2 and 3 depict the fractures seen in two specimens.

Summary

Using the biomechanical principles outlined above with close observation of the fracture patterns, it is now possible to determine the direction of a low velocity bullet crossing the skull without reliance upon the beveling of the primary entrance or exit fracture. It must be understood that the concentric fractures described here are formed by a mechanism exactly opposite, but consistent in principle, to that described by Moritz [*9*]. In effect, they are caused by pressure from within, not force applied from without.

A pictorial summary is available in Fig. 4 which originally appeared as an advertisement for Tokina® products in 1983 and depicts a .22-caliber bullet traversing an egg from left to right. Close observation shows the extensive radial fractures, fully traversing the egg, as well

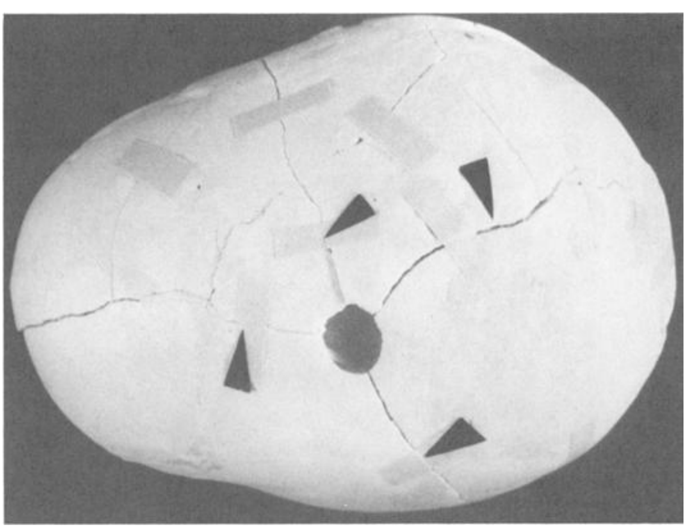

FIG. 2—*This photograph depicts a calvarium with an entrance wound and its associated fractures. Arrows point to the radial fractures, the others are concentric heaving fractures.*

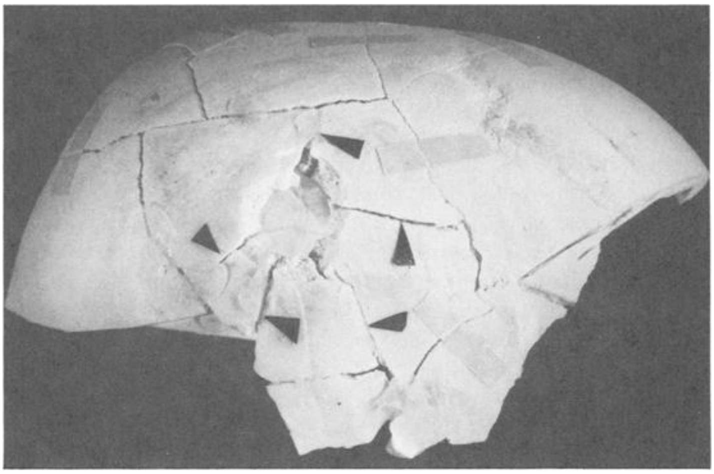

FIG. 3—*This photograph depicts a calvarium with an exit wound. Arrows indicate exit associated radial fractures arrested by preexisting, entrance associated fractures. Well-defined concentric fractures are also present.*

FIG. 4—*The principles in this study are illustrated by this photograph of an egg being shot through by a .22 LR bullet. Path is from left to right. Notice the wider radial fractures and narrow concentric heaving fractures suggesting the radial fractures preceded the concentric heaving fractures. Notice also that internal pressure is responsible for displacing fragments of both entrance and exit in the same direction—up and out. Reproduced by permission of Tokina Optical Corporation, copyright 1982.*

as multiple generations of concentric fractures created as plates of eggshell are levered away. This occurs at both entrance and exit sites, indicating how the increased pressure within the egg produces concentric heaving fractures. If the distance the fracture margins have separated are an indication of time, then it also becomes apparent that the radial fractures precede the concentric ones.

Determination of entrance and exit sites can be made at autopsy and does not require additional cleansing of the calvarium. Entrance fractures are characterized by long radial fractures originating from the initial impact site, and are not arrested by any other fracture. Heaving fractures, if present, have more generations and longer radii then exit associated fractures. If the primary entrance bevel is available, the bevel from the heaving fracture will be opposed to it. Exit fractures show radial and heaving fractures of lesser magnitude, and may be arrested by preexistent fractures associated with the entrance wound. Further, the exit bevel and heaving fracture bevel are parallel to each other. Initial examination of single-entry, no-exit wounds will quickly familiarize the pathologist with the characteristics described above. This is of great assistance before attempting to identify direction of through-and-through wounds with obscured primary fractures. The magnitude of entrance associated fractures is always greater than exit associated fractures, representing the energy drop and the calvarium's ability to relieve stress. When further supported by the observation that these lesser fractures are likely to be arrested by those of greater magnitude, the identification of entrance versus exit is readily determined.

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