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# Symmetrical Fracturing of the Skull from Midline Contact Gunshot Wounds: Reconstruction of Individual Death Histories from Skeletonized Human Remains*

**ABSTRACT:** This paper reports a bilaterally symmetrical cranio-facial fracture pattern that is observed in self-inflicted, midline gunshot wounds. Five cases of self-inflicted gunshots wounds are presented as follows: two high-powered rifle cases, two shotgun cases, and one handgun case. In all five cases the remains were either decomposing or skeletonized and submitted to forensic anthropologists. Following identification, the main focus of the anthropological examination was the analysis of perimortem trauma to the skeleton. In each case, the skull was submitted in a highly fragmented state. Nevertheless, by focusing on the pattern of perimortem cranio-facial fractures, the anthropologists contributed key information regarding the circumstances of death. The observed symmetrical cranio-facial fracture patterns in the above cases are described in detail and interpreted. The specific location of the linear fractures is discussed, as well as the theoretical rationale behind the location in terms of skeletal architecture, such as buttresses, struts, and sutures. The interpretive framework provided by this paper may prove helpful to others who are faced with similar cases of cranio-facial fracturing.

**KEYWORDS:** forensic science, forensic anthropology, skeletonized remains, skull fractures, gunshot wounds, symmetrical fractures

Nearly half of all self-inflicted gunshot deaths are midline contact wounds to the head (18.8% intraoral, 15.6% frontal, 14.1% submandibular) (1). In these cases, the muzzle of the gun is in direct contact with some part of the head at sagittal midline as the gun is fired (2). Distinguishing midline contact gunshot wounds is possible because soft tissue and skeletal tissue respond in characteristic and predictable ways. At autopsy, the forensic pathologist primarily relies on soft tissue damage to determine the cause and manner of death. However, in skeletonized or badly decomposing remains, the skeletal evidence for trauma becomes primary. As a result, forensic pathologists increasingly look to the expertise of forensic anthropologists in understanding the circumstances surrounding death (3–5).

As in all gunshot cases, locating the entrance and exit wounds in midline contact gunshot deaths is a key component of the autopsy, and is made relatively easier when the soft tissues are present and in good condition. The specific relationship between the gun and the body can often be inferred from an external examination of the skin. Evidence such as soot, skin searing, and skin tearing can allow the pathologist to identify the entrance wound location, and subdivide the event into hard-contact, loose-contact, angled-contact, and incomplete-contact (2). The location and condition of the entrance and exit wound in midline contact gunshot wounds depends on the following variables: the placement of the gun, the type of gun used, and the trajectory of the blast. For example, entrance wounds may be more difficult to locate in cases where the shotgun or rifle has been placed under the chin or in the mouth than in regions of the cranial vault (6). Also, contact wounds to the head from shotguns and high-powered rifles are incredibly destructive due to the blast of gas expelled from the muzzle upon discharge that gets transferred into the head. Despite the difference in power and velocity between a rifle and a shotgun, at close range the destructive force of each is comparable (6). On the other hand, contact handgun wounds are comparatively less destructive (6). Depending on the placement of the gun and the angle of trajectory, exit wounds in midline contact gunshot deaths can range from a small defect in the skin, to multiple tears of the skin, to complete destruction of the facial tissues.

Distinguishing midline contact gunshot wounds to the head in cases where the remains are skeletonized or badly decomposing is another matter, as the pathologist can no longer rely on the soft tissue to identify the entrance and exit wounds (2,6). In these cases, the osteological analysis of "fracture patterns may provide the evidence needed to differentiate gunshot from blunt force trauma and establish bullet direction," (7:333). In non-contact gunshot wounds, this is done by identifying the diagnostic circular defect and associated beveling of the margins of both entrance and exit wounds produced when the bullet passes through the cranial bone (2,8). Identifying entrance and exit defects in contact gunshot wounds to the head, however, is not as straightforward. While bullets fired from a long range may leave clear evidence of entry and exit, the typical features of entrance and exit wounds in bony tissue may be altered by the contact nature of the gunshot wounds. For example, reverse beveling can occur in contact gunshot wounds to the vault (9–11). In cases of submandibular or intraoral entrances, the bones

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of the skull may not exhibit typical entrance and exit wounds, and anthropologists must rely on the overall pattern of fracturing to reconstruct the individual's death history.

In gunshot wounds to the skull in general, the deceleration of the projectile within the cranial cavity results in increased pressure. In contact gunshot wounds to the skull there is an additional source of intracranial pressure that normally results in greater damage in the form of increased fracturing. In these contact "blast" events, the gas that is expelled from the muzzle of the gun upon discharge cannot dissipate into the surrounding atmosphere, so it enters the cranial cavity (2). In contact shotgun or contact high-powered rifle deaths, it is not penetration of the skull by the bullet, but the expansion of the skull due to the explosive blast, that causes most of the damage. In submandibular and intraoral gunshot wounds, there is often no well-defined circular defect through the bone. However, there still may be evidence of beveling that provides information on directionality of the blast. The fractures resulting from this increased intracranial pressure often radiate away from the entrance or exit wounds but can also lack overall pattern (2). The fractures travel away from the initial bullet wound at such high speeds that they often reach the exit-surface of the skull before the bullet (12,13). Additional fractures called concentric heaving fractures (12) may run perpendicularly between the radiating fractures of the entrance or exit wound. This is caused by the heaving-out of the bone due to the increased intracranial pressure (7,12).

In this paper we present five cases in which human remains were found in association with a gun, and the osteological examination of skeletal trauma played a key role in understanding the circumstances of death. In each case, the observed perimortem "suite of fractures" is described. Based on these cases, we suggest a possibly diagnostic bilaterally symmetrical pattern of fractures for midline contact gunshot wounds. Further, we suggest that clues to an intraoral or submandibular gunshot wound may exist in the presence of some or all of the following fractures: tripod fractures of the zygomatics, vertical fractures of the maxillae, vertical fractures of the mandibular body, a projectile path through the posterior palate, wedge-fractures of the mandible, and symmetrical fracturing of the supraorbital region. Finally, we propose a theoretical explanation for the specific location of fractures in these cases.

## Bilaterally Symmetrical Pattern of Fractures

A potentially diagnostic symmetrical pattern of cranio-facial fractures has been observed in midline contact gunshot wounds to the head. This pattern has been informally recognized by forensic pathologists (even though the authors are hard-pressed to find reference to it anywhere in the literature), and has been formally recognized by one forensic anthropologist (14). The fact that midline gunshot wounds, whether submandibular, intraoral, or midfrontal, produce bilaterally symmetrical fractures is not surprising, as the skull is a bilaterally symmetrical, though geometrically complex, anatomical element (15). Therefore, in cases where the focus of force is along the sagittal midline of the skull, it is only to be expected that, within a certain range of variation, the two sides of the skull respond to the trauma in the same way.

Symmetrical fracturing of the skull is commonly observed to occur from blunt forces (16). Le Fort I, II, and III fractures are classic examples of symmetrical fracturing of the face and illustrate the influence of facial buttresses in directing the path of fractures (17). Basilar ring fractures have also been recognized as symmetrical in nature (16). Child abuse often results in bilateral horizontal fractures of the skull that are likely caused by blows to the top of the head, a probable midline event (18). Experimentally, symmetrical cranial fractures have been produced by midline blows to the occipital bone (19).

## Theoretical Attempts to Explain Fracture Location

Operating within a framework of symmetry, the specific locations of skull fractures in midline contact gunshot wounds to the head may theoretically be predictable. A theoretical body of work does exist which attempts to explain how the skull responds to blunt force trauma. Early experimental research on human cadaver heads focused on predicting the fracture site in specific blunt force impacts (20). Gurdjian and co-workers also experimentally investigated fracture propagation and suggested that linear fractures are commonly seen in the skull as the result of indirect trauma in the area of out-bending of the cranial bones in response to a direct impact (20–24). Recent experimental research on fracture propagation by Kroman (25), however, indicates that fractures initiate at the point of impact and radiate out from there.

Further experimental research on the forces required to fracture bones of the skull has shown that a pressure of 3.1 to 5.2 Mpa (450–750 psi) is required to produce a linear skull fracture in cadaver heads (26,27). The skull, however, is not uniform in its composition, meaning that the fracture tolerances of cranial bones differ across the skull. Automotive industry testing has experimentally generated data on the force to fracture tolerance of specific bones of the skull (28–30). Yet, to our knowledge, no studies to date have assessed the variation of fracture tolerances within specific bones. Because we cannot explain the location of a fracture within a bone by biomechanical experimental data, other tools of analysis must be utilized. The location of sutures, foramina, and theoretical struts and buttresses in the skull is one such tool that can contribute to an understanding of fracture patterns.

It is generally accepted that linear skull fractures will "take the path of least resistance and will propagate until its energy is dissipated," (7:337). This means that cranial fractures often involve sutures (31), sinuses, and foramina, especially the foramen magnum (15), because of the weakness that results from interruption of the integrity of the bone. Recent work on the biomechanical properties of foramina in bone by Gotzen, Cross, Ifju, and Rapoff (32), however, reports that bone surrounding a foramen actually works to dissipate force around the structure. This indicates that perhaps foramina are not the weak anatomical structures as once thought.

There have been several attempts to theoretically explain the location of linear skull fractures (7,17,33–36. Galloway (1999) has discussed a system of cranial buttresses proposed by Le Count and Apfelbach (1920) and a system of facial struts proposed by Gentry and associates (1983), while the contributions of Rogers (1982) and Moritz (1954) to facial and vault buttressing, respectively, were discussed by Berryman and Symes (1998) (Fig. 1). Both discussions include the patterns of facial fracturing described by Le Fort (1901).

The Le Count buttresses represent vertical arches of the skull where the bone is thicker and, therefore, stronger than in other areas. These buttresses are located in the midfrontal, midoccipital, parietosphenoidal, and parietopetrous regions. The buttresses of the vault proposed by Moritz are consistent with, but more localized than, those described by Le Count. The reinforced areas are located in the midfrontal, midoccipital, anterior temporal, and posterior temporal regions. The facial buttresses proposed by Le Fort and discussed by Rogers are located along the alveolar ridges, the malar eminences, and the nasofrontal process of the maxilla. These areas of the face are structurally stronger and resist fracture, resulting in the patterns of facial fracturing that have been described as Le Fort I (separation of the alveolar portion of the maxilla from the

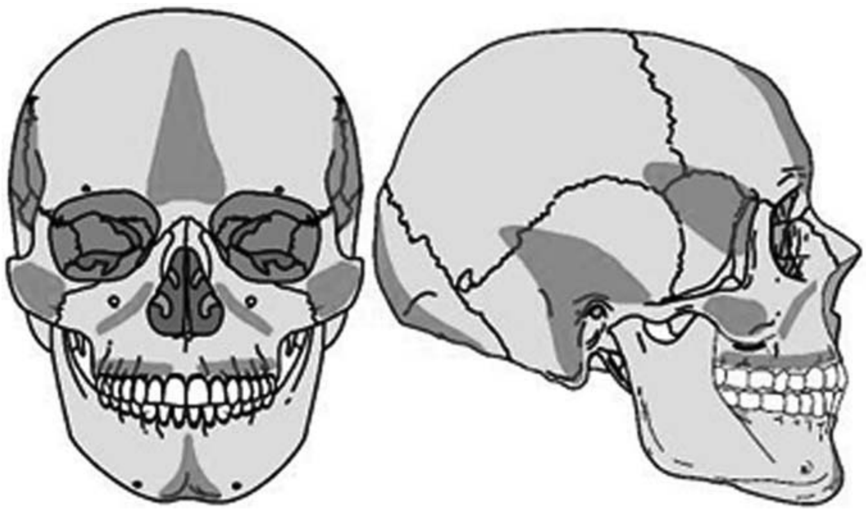

FIG. 1—*Cranial and Facial Buttressing [after Moritz (29) and Rogers (17)].*

face), Le Fort II or pyramidal (separation of the middle of the face from the rest of the skull), Le Fort III (separation of the skull near the supraorbital margins) and tripod fractures (isolation of the zygomatics). Gentry et al.'s system consists of horizontal, vertical, and coronal struts in the face that are less susceptible to fracturing than the rest of the splanchnocranium. While fractures certainly can, and do, occur in buttressed areas, this most often involves fractures that are running perpendicularly to the buttress and cross through it, as opposed to running within it. Further, "fractures that encounter the buttresses at an oblique angle tend to be diverted toward structurally weaker areas," (15:70).

Fractures of the cranium also appear to be influenced by the "grain" of the cortical bone which reflects the predominant direction of the fibrous tissue of the osseous lamellae (37,38). The grain of the cranial bones has been illustrated by using the Benninghoff "split-line" technique (39,40) (Fig. 2). Benninghoff (1925) showed histologically that the split-line orientation corresponded to the direction of organization of the majority of the Haversian systems in that region of bone. The orientation of the Haversian systems within the bones may be a functional response to countering tangential shear forces. Biomechanical studies have found that the split-line orientations display consistent patterns depending on the specific region of the cranium. The cortical bone of the neurocranium (except for the base) shows a primarily random grain pattern (37), while the neurocranium base and the splanchnocranium show definite grain patterns (37,41–43). These split-line orientations in the crania may correspond to the structural orientation of the bone in response to mechanical stresses, a pattern that appear to be related to resisting pressure and tension forces primarily due to mastication.

It is proposed here that these systems, normally used to characterize and understand blunt force trauma, can be valuable in the analysis of fracture patterns from contact gunshot wounds to the head. The applicability of skull buttresses, struts, sutures, and split-line orientation to contact midline gunshot wounds to the head (including those produced by shotguns, high-powered rifles, and handguns) will be demonstrated here.

## Case Descriptions

In the descriptions of cranio-facial fracturing observed in each case, only the major fractures will be enumerated. For a more complete understanding, please see the referenced figures.

### Case 1—Intraoral Rifle Wound

In 1998 the body of an adult male was discovered in the front seat of his car. At the time of discovery, the decedent was in the driver's seat, with a .300 rifle positioned between his legs and his left thumb on the trigger. The condition of his head indicated massive trauma consistent with injury from a high-powered firearm. The roof of the vehicle directly above the presumed position of the decedent at the time of death displayed apparent projectile damage. The remains were embalmed and buried. In February 2004, because of family questions about the manner of death, the remains were disinterred and an autopsy was performed. The autopsy revealed circum-oral lacerations of the lips consistent with death due to an intraoral gunshot wound from a high-powered rifle, such as the one initially found with the body. Among the autopsy findings was a pattern of blood drips from the mouth indicating a vital reaction to the injury and that the individual was alive at the time of injury. There were no findings at autopsy that were inconsistent with suicide by self-inflicted intraoral rifle trauma. Subsequent to the autopsy, the cranium was processed and reconstructed from at least 36 fragments (Fig. 3).

#### *Etiology of Fractures*

From the autopsy and direct observation of the cranial pieces, it is clearly apparent that the entrance wound is in the hard palate of the maxillae. An exit wound, with clear external beveling is visible on the right parietal bone, 32 mm posterior to bregma. The semicircular defect is bordered on the midline by the sagittal suture. Thus, the trajectory of the missile was inferior to superior, from the bony palate to the near-midline of the skull about midway along the sagittal suture.

#### *Missing Segments*

Though the skull was mostly complete, there were several elements missing. The body of the sphenoid was not recovered, along with the palatine bones and the majority of the palatine process of the maxillae. A fragment from the center of the right parietal bone was not recovered. Also missing from the right parietal bone is a roughly circular piece approximately 15 mm in diameter. It is located approximately 32 mm posterior to the cranial landmark bregma, the sagittal suture forms its medial edge, and beveling is

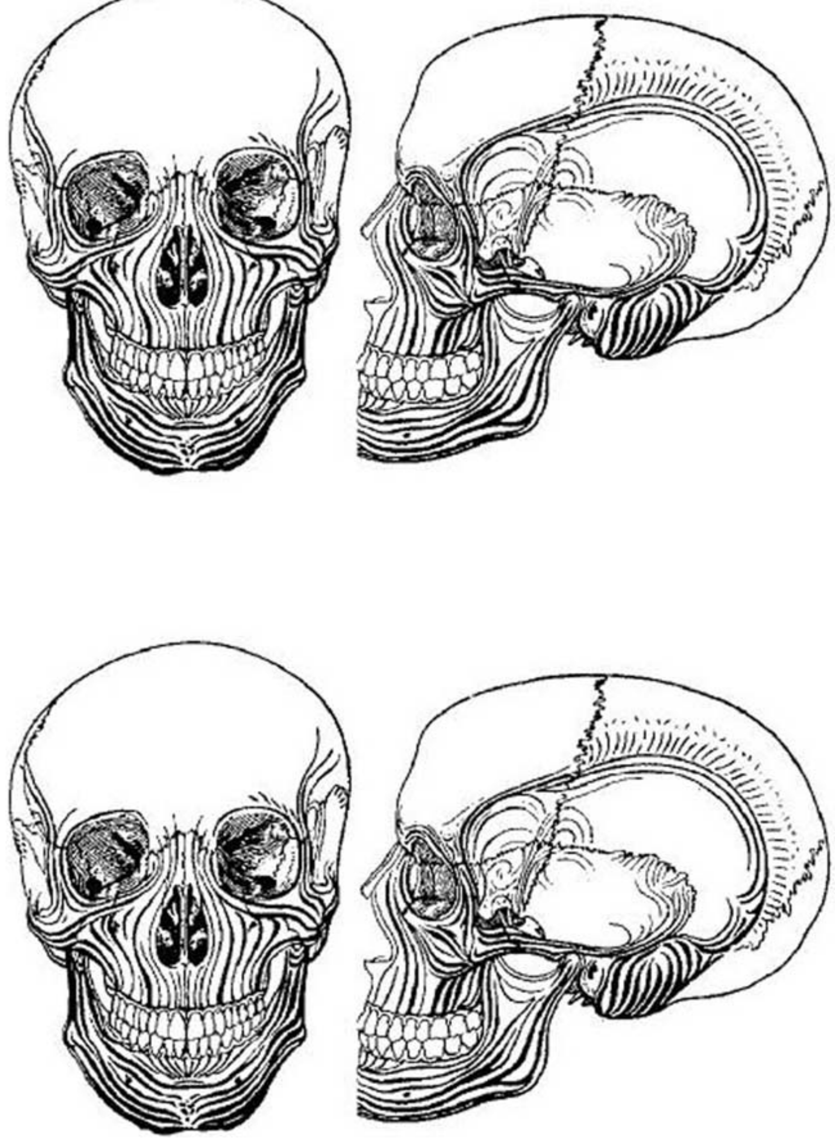

FIG. 2—*Split-line Pattern of the Skull [after Benninghoff (33)].*

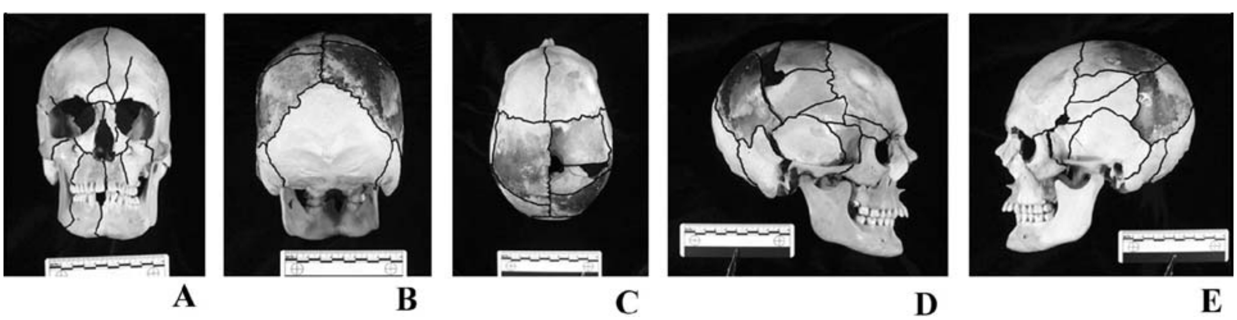


FIG. 3—*Major cranio-facial fractures from Case 1: (a) Anterior aspect; (b) Posterior aspect; (c) Superior aspect with exit wound; (d) and (e) Lateral aspects.*

present along the outer surface. This is the location of the exit wound.

*Fractures of the Mandible*

The mandible exhibits a vertical fracture along the midline. The right side is fractured through the body, separating the ascending ramus from the alveolar process. Just posterior to the mental foramen, this fracture sweeps back behind the second molar.

*Fractures of the Maxillae*

The right and left maxillae are separated by a midline vertical fracture. Bilateral vertical fractures are also present. On the right side, the fracture originates between the second premolar and the first molar. On the left side, vertical fractures extend from the alveolus of the first premolar and from the mesial edge of the second molar. Oblique fractures are present on the right and left maxilla, extending from the lateral edges of the nasal aperture to the inferior border of the right and left orbits. On the left side, a fracture is present just inferior to the nasomaxillary suture, extending from the nasal aperture to the inferomedial corner of the left orbital margin.

*Fractures of the Zygomatics*

Tripod fractures of the zygomatics are present bilaterally. On both the right and left sides, these fractures are diastatic along the zygomaticomaxillary, zygomaticofrontal, and zygomaticotemporal sutures.

*Fractures of Sphenoid*

The sphenoid was extensively fractured. Only the greater wings could be incorporated into the reconstructed skull. These elements were separated from the frontal and temporal bones by diastatic fractures. Miscellaneous fragments were recovered.

*Fracture of the Nasal Bones*

A midline diastatic fracture separates the right and left nasal bones. A fracture also occurs along the nasofrontal suture.

*Fractures of the Frontal Bone*

The frontal bone exhibits several bilaterally symmetrical fractures. Diagonal fractures extend from the superomedial corners of the right and left orbital margins, converging toward the midline just above the cranial landmark glabella. At the junction of these symmetrical fractures, a midline fracture originates and extends posteriorly along the frontal, terminating at the coronal suture. Minor, non-symmetrical fractures are also present. On the right side, a roughly horizontal fracture extends from the orbital margin just superior to the zygomaticofrontal suture to the coronal suture. On the left side, a fracture extends superiorly from the superior border of the orbit, dissipating within the frontal bone.

*Fractures of the Parietals*

A midline, diastatic fracture of the sagittal suture separates the right and left parietal bones. The parietal bones are separated from the temporal bones by bilateral diastatic fractures. On the right side, the exit defect with external beveling is located along the sagittal suture in the right parietal. A fracture extends laterally from the exit wound. Just posterior, a second fracture extends laterally from the midline, terminating at the right squamosal suture. Two roughly parallel horizontal fractures are present on the right parietal bone. These fractures run anterior-posteriorly between the coronal suture and fracture discussed above. On the left side, two fractures extend laterally from the sagittal suture. These fractures meet near the parietal boss and run extend anteriorly to the coronal suture. A horizontal fracture extends between this fracture and the coronal suture, while a roughly vertical fracture runs between this fracture and the left squamosal suture.

*Fractures of the Temporals*

One the right and left sides, bilaterally symmetrical fractures separate the mastoid processes from the temporal bones.

*Fractures of the Occipital*

The occipital bone has been isolated from the rest of the cranium by a diastatic fracture along the extent of the lambdoidal suture. On the basilar aspect, a midline fracture extends anteriorly from the foramen magnum.

### Case 2—Intraoral Rifle Wound

The remains of a 28-year old Caucasian male in an advanced state of decomposition were recovered from a rural scene in New Mexico on July 1, 1996. The decedent died as a result of an apparent self-inflicted gunshot wound. At the scene, a .303 caliber rifle was found in association with the remains. The nearly complete skull was heavily fractured and shattered into many separate elements. A meticulous cranial reconstruction was conducted to assess the trajectory of the projectile. On September 17, 1999, nine additional cranial fragments were recovered at the scene and incorporated into the previously reconstructed cranium (Fig. 4).

*Etiology of Fractures*

Despite meticulous reconstruction of the cranium, the exact location of the entrance wound could not be ascertained. However, the extensive fracturing of the maxilla, the posterior orientation of the fractures of the frontal bone, the missing portions of the palatines and sphenoid, the damage to atlas, and the region of the exit wound indicates that the gunshot wound was probably intraoral.

*Missing Segments*

Though the skull is very complete, a large, irregularly shaped portion of the occipital bone was not recovered. This element is located 49 millimeters inferior to the cranial landmark lambda, and

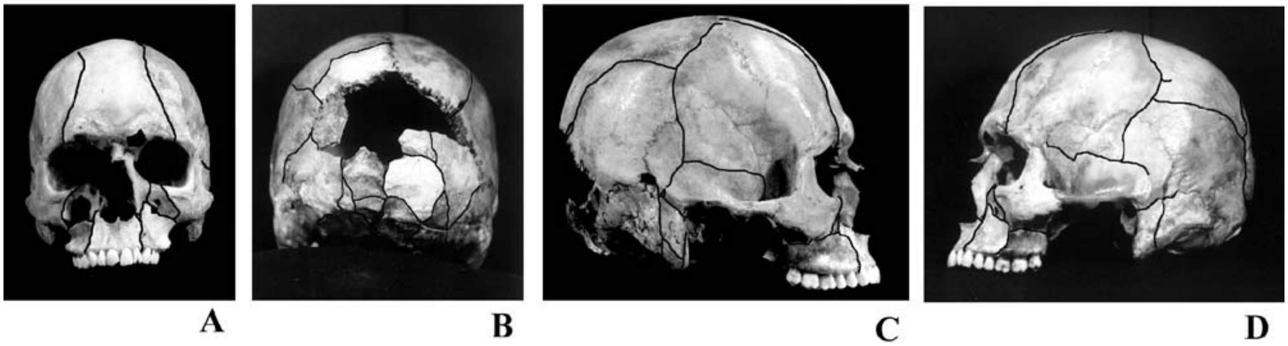


FIG. 4—*Major cranio-facial fractures from Case 2: (a) Anterior aspect; (b) Posterior aspect with probable exit region; (c) and (d) Lateral aspects.*

is bordered along its upper edge by the lambdoidal suture. External beveling is evident along the inferior arc of the defect, indicating that this mid-occipital fragment is the location of the exit wound. Portions of the right maxilla near the nasal aperture, the horizontal portions of the palatines, and the body of the sphenoid were also missing.

*Fractures of the Mandible*

A midline symphyseal fracture extends from the alveolus to the apex of the mental trigone. The fracture then splits along each side of the trigone, creating a triangular wedge.

*Fractures of the Maxillae*

Bilateral vertical fractures extend from the alveolar process to the lateral edges of the nasal aperture. On the right side, this fracture begins just distal to the canine, and on the left side the fracture is located just distal to the lateral incisor. An additional vertical fracture extends from the alveolus superior to the left first molar. Bilaterally, fractures extend horizontally from the vertical fractures, coursing inferior to the zygomatic arches, to the posterior edges of the right and left maxillae. The maxillae also exhibit bilateral fractures just anterior and parallel to the zygomaticomaxillary sutures.

*Fractures of the Frontal*

The frontal exhibits bilaterally symmetrical fractures extending vertically from the superior orbital margins to the coronal suture.

*Fractures of the Parietals*

The right and left parietals exhibit symmetrical fractures that are roughly vertical in orientation. These fractures begin at the coronal suture near the midline, arc posteriorly, and extend onto the temporals. On the right side, this fracture continues to the tip of the mastoid process, while the fracture on the left side terminates at its junction with the fracture of the temporal, discussed below. Bilaterally, horizontal arc fractures extend from the vertical fractures posteroinferiorly to the lambdoidal suture. On the left side, a coronal fracture extends between the arc fracture and the sagittal suture.

*Fractures of the Temporals*

Bilaterally, fractures extend from the anterior edge of the sphenoid bone onto the right and left temporals, where they continue posteriorly to meet the vertical fractures of the parietals. This junction results in a Y-shaped fracture pattern on the right and left temporal bones. The fracture of the right temporal terminates at the vertical fracture. The fracture of the left temporal continues past the junction and arcs posteriorly onto the mastoid process. Both the right and left mastoid processes are "outlined" by fractures.

*Fractures of the Occipital*

The occipital bone is extensively fractured, containing at least 13 distinct fragments, and a large portion of the bone was not recovered. A vertical fracture is located along the midline, with bilaterally symmetrical fractures running vertically on either side. Fracturing of the basilar region of the occipital bone occurred concurrently with damage to the first cervical vertebra. Though the atlas was complete, it was fractured into four pieces.

**Case 3—Submandibular Shotgun Wound**

In September of 2000, skeletonized human remains were recovered from a wooded area in mid-Michigan by a law enforcement search team. At the scene, a shotgun was found in association with the remains. Osteological analysis determined that the remains were those of an adult male of European ancestry, and a positive identification was made through comparative radiography. The cranium and mandible were recovered in a fragmentary, but mostly complete, state. At least 45 distinguishable fragments were recovered and reconstructed. The facial portion of the skull (anterior to the coronal suture) was highly fragmentary, whereas the skull was in one piece posterior to the coronal suture, exhibiting only incomplete fractures (Fig. 5).

*Etiology of Fractures*

The symmetrical fracture pattern observed in this case is consistent with a single explosive force to the skull, such as one that could be generated by the recovered shotgun found in association with the skeletonized remains. Based on the location of the probable entrance and exit wounds, the orientation of beveling on the palate and frontal bone, and the pattern of mandibular fracturing, the gunshot entry is believed to be submandibular and the directionality of the projectile inferior to superior. While the symmetrical nature of the fractures is consistent with other midline contact gunshot wounds, such as intra-oral, the intact vault posterior to the coronal suture and the probable exit wound located in the frontal bone makes this possibility highly unlikely. The wedge-fractures of the chin may also indicate that the origin of the blast is likely submandibular.

*Missing Segments*

Though the skull was mostly complete, two elements were missing. A bilaterally symmetrical bone segment from the inferior aspect the skull was not recovered, comprised of part of the right and left maxillae, the right and left palatines, the vomer, and part of the

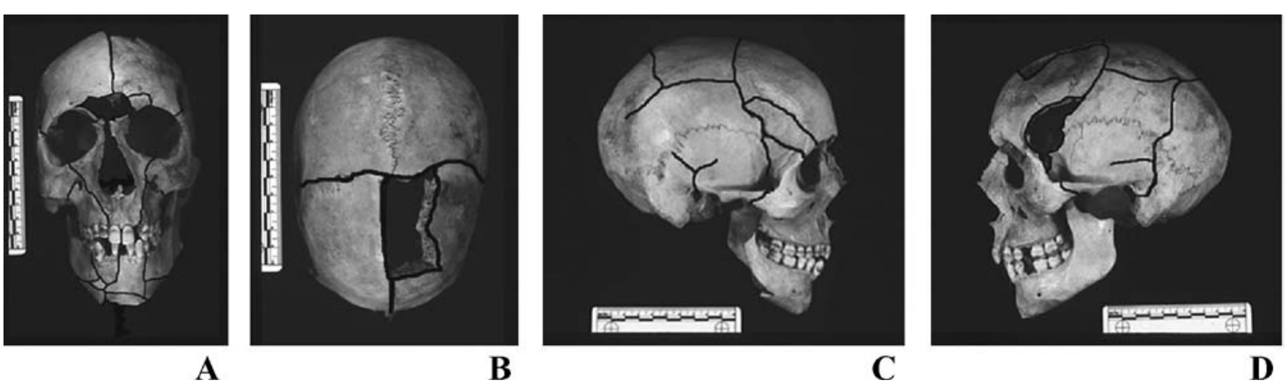


FIG. 5—*Major cranio-facial fractures from Case 3: (a) Anterior aspect; (b) Superior aspect with probable exit region; (c) and (d) Lateral aspects.*

sphenoid. The missing segment measures 34 × 43 mm, and its existing borders show beveling on the inner surface. This may represent the location of the first bony entrance of the gunshot wound.

A roughly rectangular segment from the frontal bone was also not recovered. This missing piece is located just left of the midline near the cranial landmark bregma, measures 22 × 51 mm, and extends across the coronal suture to include a small portion of the parietal bones. The existing borders are beveled on the outer table, which indicates that this is the probable location of the exit wound.

*Fractures of the Mandible*

The inferior border of the body exhibits three triangular wedge-fractures that have been "blown out" of the chin. The central fracture spans the midline and the adjacent fractures on either side are roughly bilaterally symmetrical. A fracture of the right ascending ramus has separated it from the mandibular body. The condyle and angle were not recovered. On both the right and left sides, vertical fractures are located interproximally between the canine and first premolar and extend inferiorly to end on the superior border of the wedge-fractures. A third vertical fracture is observed slightly right of midline, between the right central and right lateral incisors.

*Fractures of the Maxillae*

Vertical fractures of the right and left maxillae exhibit bilateral symmetry as well. On the left side, the fracture extends from the distal side of the lateral incisor. On the right side, the fracture is located interproximally between the central and lateral incisors. These fractures terminate on the inferior border of the orbits. The right and left maxillae both exhibit oblique fractures just medial to the zygomaticomaxillary sutures, separating the maxillae from the zygomatics. The maxillary palatine process has symmetrical parasagittal fractures on the right and left sides, extending from between the lateral incisors and the canines to a transverse fracture anterior to the palatomaxillary suture.

*Fractures of the Zygomatics*

Tripod fractures (15) of the zygomatics are present bilaterally. On the right side, the tripod fractures occur diastatically along the zygomaticotemporal suture and the zygomaticofrontal suture. The anterior border is formed by the oblique fracture of the right maxilla discussed above. A diastatic fracture of the zygomaticotemporal suture also occurs on the left side, forming part of the left tripod. The superior and anterior borders of the left tripod fracture are formed by a lateral fracture of the frontal bone and the oblique fracture of the left maxilla, respectively.

*Fracture of the Sphenoid*

The sphenoid exhibits diastatic fractures along its anterior aspect and right frontosphenoidal suture. The right greater wing is fractured along it posterior edge and the left greater wing is fractured near its superior edge. These fractures extend onto the parietals where they continue as the coronal fracture. The central portion of the sphenoid was not recovered.

*Fracture of the Nasal Bones*

There is a midline diastatic fracture of the nasal suture. The right nasal bone was not recovered.

*Fractures of the Frontal Bone*

A midline vertical fracture extends the entire length of the frontal bone. The frontal also displays a horizontal arc fracture in the supraorbital region near the cranial landmark nasion. This fracture terminates at the superomedial borders of the right and left orbits. On the right, a fracture extends from this horizontal fracture to the frontomaxillary suture. Bilateral fractures were observed on the right and left sides of the frontal bone near the zygomaticofrontal sutures. On the right this fracture is diastatic, while on the left it is just superior to the suture. The right side fracture continues diastatically along the frontosphenoidal suture and a second fracture runs parallel to this one, roughly along the temporal line. Both of these frontal fractures terminate in a coronal-plane fracture of the right parietal bone. The left side fracture continues posteriorly, approximating the temporal line until it ends at the coronal fracture of the left parietal. The bone fragment bounded by these fractures was not recovered.

*Fractures of the Parietals*

A coronal-plane fracture originating from the sphenoidal fractures discussed earlier spans across the right and left parietal bones. On the right side, this fracture becomes diastatic as it approaches the midline. It is at this fracture that the fragmented facial skeleton is separated from the intact posterior portion of the skull. Both the right and left parietals exhibit incomplete lateral fractures that extend from the coronal fracture, running posteriorly and then inferiorly and giving rise to branches that extend superiorly. On the right, the lateral fracture and its superior branch are confined to the parietal bone. On the left, the lateral fracture terminates in an incomplete fracture from the temporal bone and the superior branch terminates on the sagittal suture near the cranial landmark lambda.

*Fractures of the Temporals*

The right and left temporal bones exhibit incomplete Y-shaped fractures. The right-side anterior branch dissipates in the temporal bone, while the posterior branch terminates at the parietotemporal suture. On the left, the anterior branch dissipates in the temporal bone, while the posterior branch continues over the parieto-temporal suture to meet with the lateral fracture of the left parietal.

*Fractures of the Occipital*

The basi-occiput exhibits an incomplete midline fracture extending from the anterior margin of the foramen magnum. Bilaterally symmetrical incomplete fractures of the occipital extend posteriorly from the lateral margins of the foramen magnum.

### Case 4—Possible Submandibular Shotgun Wound

In January of 2003, hunters discovered skeletonized human remains and an associated shotgun in a wooded area of the western lower peninsula of Michigan. The remains were those of an adult male of European ancestry. A positive identification was made through comparative mitochondrial DNA analysis. The cranium and mandible were recovered in a fragmentary and incomplete state, with only 26 skull fragments present. As a result, it was not possible to reconstruct the cranial vault. The highly fragmentary nature of the recovered skull makes precise description of the location and course of the fractures much more difficult, and must sometimes be replaced by a general description of the resultant fragments (Fig. 6).

FIG. 6—*Skull fragments from Case 4.*

*Etiology of Fractures*

Despite the fact that most of the cranial vault is missing, the fragments that were recovered exhibit a bilaterally symmetrical fracture pattern very similar to that seen in Case 3, which lead the authors to believe that a midline contact gunshot wound was the cause of the skeletal trauma. The fragmentary nature of the remains, most significantly the missing vault and lack of probable entrance and exit sites, makes any specification of the shotgun wound as intra-oral or submandibular very difficult. In fact, without the comparative value of Case 3, the significance of the fracture pattern seen in this case may not have been recognized as indicative of a midline contact gunshot wound.

*Fractures of the Mandible*

The mandible exhibits a wedge-shaped fracture centered below the left canine that has appears to have been "blown out" from the chin. A vertical fracture of the body extends from the canine's alveolar tip to the wedge-fracture below. There is a vertical fracture of the mandibular body near the gonial angle, just distal to the right second molar.

*Fractures of the Maxillae*

A vertical midline fracture coursing superiorly from between the central incisors separated the right and left maxilla bones. Oblique fractures on both sides run roughly parallel to the zygomaticomaxillary suture. On the right, this fracture is distal to the first molar, while the left-side fracture is distal to the first premolar. These fractures contribute to the formation of the tripod fractures of the zygomatics.

*Fractures of the Zygomatics*

The right and left zygomatics exhibit tripod fractures. The anterior borders of the tripod fractures are formed by the oblique fractures of the maxillae. The superior and posterior borders are formed on the right and left sides by diastatic fractures of the zygomaticofrontal and zygomaticotemporal sutures.

*Fractures of the Frontal*

In the right and left supraorbital regions of the frontal bone, medial and lateral vertical fractures extend superiorly from the superior orbital margins. On both sides, horizontal fractures extend between these vertical fractures, creating bilaterally symmetrical rectangular fragments of the frontal. Two large bone segments were recovered that contained part of the coronal suture. One is composed of frontal and left parietal bone and is roughly rectangular. The second fragment is composed of frontal and right parietal bone and is more triangular in shape.

*Fractures of the Parietals*

In addition to the large fragments containing part of the right and left parietals discussed above, a large fragment of the right parietal was recovered. The superior edge is an arc fracture. The fracture along the inferior edge courses through the corner of the greater wing of the sphenoid and onto the right temporal bone. The fracture becomes diastatic along the parietotemporal suture, terminating as it intersects with the arc fracture.

*Fractures of the Occipital*

Five small, highly bilaterally symmetrical fragments of the occipital bone were recovered. The central fragment is composed of the basi-occiput, which was isolated by fractures along its anterior, posterior, and lateral edges. Fractures around and between the right and left occipital condyles have separated them from each other and from the rest of the skull. The right and left anterior fragments are bounded by fractures through the greater wings of the sphenoid and parts of the occipital bone. These fragments contain the medial and lateral pterygoid plates and the foramen ovale.

**Case 5—Mid-Frontal Pistol Wound**

The remains of a 24-year old Caucasian male in an advanced state of decomposition were recovered at a forested rural scene in New Mexico on September 29, 1975. The decedent died as a result of an apparent self-inflicted gunshot wound to the frontal. At the scene, a .38 caliber automatic pistol was found in association with the remains. The nearly complete skull was heavily fractured and shattered into many separate elements. A meticulous cranial reconstruction was conducted to assess the trajectory of the projectile (Fig. 7).

*Etiology of Fractures*

The entrance wound is evident in the midfrontal. The defect is located along the midline just superior to the frontal sinus. It displays the characteristic "punched-out" appearance typically seen in gunshot wounds to the skull. The exit wound is apparent in the midoccipital region. The defect is located along the midline, and is beveled along the outer table. The location of the entrance and exit wounds clearly indicates that the gunshot wound was to the midfrontal region.

*Missing Segments*

A roughly rectangular segment of the frontal bone, continuous with the entrance defect and including the superomedial margin of the right orbit, was not recovered.

*Fractures of the Mandible*

The mandible displays bilateral fractures of the body in the proximity of the third molars.

*Fractures of the Maxillae*

Fractures extend from near the lateral borders of the nasal aperture to the posterior edges of the right and left maxillae. Bilaterally symmetrical vertical fractures course between these fractures and the inferior orbital margins.

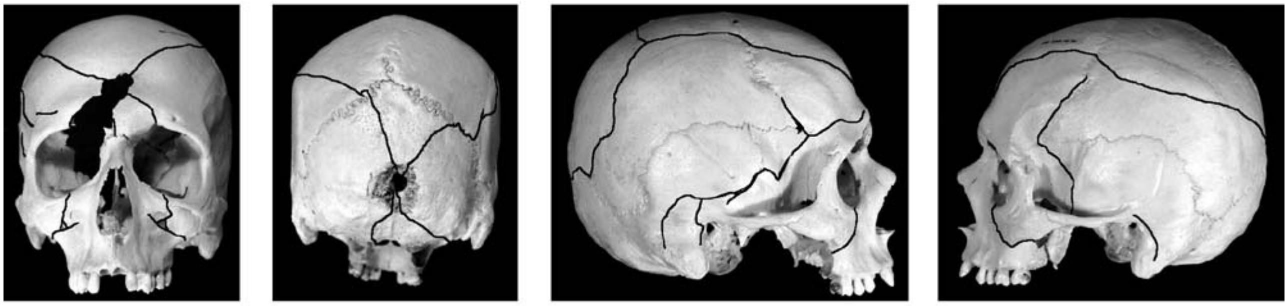


FIG. 7—*Major cranio-facial fractures from Case 5: (a) Anterior aspect with entrance wound; (b) Posterior aspect with exit wound; (c) and (d) Lateral aspects.*

*Fractures of the Frontal*

Several linear fractures radiate away from the entrance wound, located along the midline of the anterior frontal bone. Bilaterally, fractures extend to the superior orbital margins. Symmetrical fractures extend obliquely toward the coronal suture, continuing onto the right and left parietals. A midline fracture courses between the entrance defect and the nasofrontal suture. Bilaterally, the frontal bone displays diastatic fractures of the coronal suture that originate from the superior anterior corners of the sphenoid. These fractures dissipate before they juncture with the oblique radiating fractures.

*Fractures of the Parietals*

The bilateral oblique fractures of the frontal bone continue posteriorly across the coronal suture onto the right and left parietals. On the right side, the linear fracture gives off a small superior branch, before arching toward the lambdoidal suture, where it becomes diastatic for a short length. The left-side fracture does not branch in its course between the frontal bone and the lambdoidal suture.

*Fractures of the Temporals*

From the superior anterior corners of the sphenoid, fractures extend across the right and left greater wings to the temporosphenoidal sutures. On the right side, this fracture crosses the suture and continues posteriorly over the temporal bone, arcing inferiorly to run behind the right mastoid process. A branch of this fracture runs just posterior to the external auditory meatus, along the anterior margin of the right mastoid process. On the left side, the fracture remains diastatic, extending posteriorly along the left temporosphenoidal suture.

*Fractures of the Occipital*

Bilaterally symmetrical linear fractures radiate away from the exit wound, located in the midoccipital region. Superiorly, fractures extend between the exit defect and the lambdoidal suture, where they course diastatically to meet the right and left parietal fractures. Inferiorly, oblique fractures course onto the basal aspect of the skull.

**Discussion**

In three of the above cases, the skulls did not exhibit the classic gunshot entry and/or exit injuries, which made the reconstruction of those individual death histories quite challenging. The skulls in those cases, however, did exhibit important evidence in the form of bilaterally symmetrical fracture patterns. We believe that this distinctive pattern is the result of a contact midline gunshot wound to the head, in which there is a centralized explosive dispersion of gases. This hypothesis is supported by the symmetrical fracture pattern seen in Case 1, which was determined by autopsy, and corroborated by a clear exit wound, to be a midline event, and by Case 5, which has entrance and exit wounds located along the midline of the skull.

While the five cases presented here are similar in the overall symmetry of their craniofacial fractures, Case 3 and Case 4 are also similar with regard to specific fractures. The similarities can be traced in a step-wise fashion of the explosive event from the mandible, which exhibits wedge-fractures of the chin and vertical fractures of the body, through the maxillae and facial region, where vertical fractures of the maxillae, oblique fractures near the zygomaticomaxillary suture, and bilateral tripod fractures of the zygomatics are observed in both cases, and into the cranium, where symmetrical fracturing of the supraorbital region occurs in Case 3 and Case 4. Interestingly, where variation is seen in these fractures, the symmetrical theme is maintained. For example, the vertical fractures of the maxillae are bilaterally symmetrical in Case 3, with fractures occurring to the right and to the left of the midline. Alternatively, Case 4 exhibits midline symmetry in its vertical fracture along the intermaxillary suture. The opposite relationship is seen in the supraorbital region, where fracturing created a midline fragment in Case 3 and bilaterally symmetrical fragments in Case 4. The overall similarity between these cases in the symmetrical fracture patterns was highlighted by the shared characteristics described above. This was what allowed for the reconstruction of the death history in Case 4, where the skeletonized remains were too fragmentary and incomplete to reach a detailed conclusion from an isolated analysis.

The differences between the fracture patterns of Case 3 and Case 4 do not diminish the utility of the comparison. Variation is to be expected, even from the same event, as slight differences in the circumstances, such as the angle of the gun to the skin's surface, the size of the blast produced, or individual differences in soft tissue and bone composition, make each source of trauma unique. The craniofacial fracture patterns observed in these cases are similar, not identical, just as the events that produced them were similar, not identical.

Setting the specific commonalities aside, just the extent of facial fracturing in Case 4 ties it more closely to the submandibular Case 3 than to the intraoral Case 2. While the vault exhibits the majority of the damage in Case 2, the trauma to the facial region in Cases 3 and 4 is much more extensive. In Case 1, both the face and vault are extensively fractured. This difference can be linked to the focus of the blast in terms of the orientation of the gun. In the intraoral gunshot wound of Case 2, the gun was held more-or-less horizontally, and the blast of gas from the muzzle is "aimed" more toward the back of the vault. This is reflected in the location of the probable exit in the occipital region, the predominance of fractures in the vault, and the more intact facial skeleton. Conversely, in a submandibular gunshot wound, the gun is held more-or-less vertically, and the blast of gas from the muzzle is "aimed" more toward the front of the vault. The expansion of gasses, therefore, results in more damage to the facial region, while the back of the skull is subjected to less force. This is reflected in the location of the probable exit in the frontal region, the extensive fracturing of the face, and the presence of only incomplete fractures posterior to the coronal suture. Case 1, representing a "vertical" intraoral gunshot wound, represents a combination of the other two events, with extensive facial and vault fracturing and an exit wound posterior to the coronal suture, but not in the occipital region either.

Other similarities and differences may prove illuminating as well. While Case 5 does not exhibit vertical fractures of the maxillae, this type of fracture is present bilaterally in Cases 1, 2, 3, and 4. It may be significant that Case 5 is different in that the focus of the force is to the midfrontal bone, while the other cases presented here have a much lower origin of the blast (submandibular or intraoral). Case 5 also differs by the presence of clear, typical entrance and exit wounds. Typical entrance and exit wounds are not present in Cases 3 and 4, while Cases 1 and 2 clearly possess typical exit wounds, but do not possess typical entrance wounds. Case 5 is also the only case to display typical radiating fractures from the points of entry and exit. These differences may arise from the fact that the weapon used in Case 5 was a low-velocity handgun, in contrast to a rifle (Case 1 and 2) and a shotgun (Case 3 and Case 4). The destructive force of a high-velocity rifle and a shotgun, which mimics a high-velocity event in contact situations (44), is much greater than that of a handgun, which may explain why the exit defects are so much bigger and more irregular than is usually seen in gunshot wounds of the skull.

### Buttresses, Struts, and Sutures

In the case of a contact gunshot wound, the expansive gases of the blast enter the restricted space of the cranial vault, and the increase in intracranial pressure causes fragmentation and fracturing of the skull (6,2). Because the weaker parts of the skull are more susceptible to breakage, the secondary radiating fractures are "distributed along paths of least resistance," (7:350) and tend to stop when they juncture with a previously created fracture, which allows for the dissipation of the force driving the fracture (8). These five cases may illustrate that this type of fracturing does not occur randomly, but rather along predictable planes, as the fractures are influenced by the anatomy of the skull. Theoretically, the lines of fracture most likely occur in areas that are structurally weaker, which give way under the force of such explosive events. Thus, buttresses, struts, sutures, split-line orientation, sinuses, and foramina are important features of the skull that influence how it fractures under conditions of increasing intracranial pressure (15,38,43).

An examination of the above forensic anthropology cases in relation to the proposed areas of strength and weakness discussed earlier has utility in understanding the fracture patterns produced. When using these systems in an analysis, it is important to remember that they are guidelines, not absolute standards (15), and the complexity of a specific pattern cannot be reduced to the influence of these systems. That is, while buttresses, struts, and sutures *influenced* the paths of the fractures seen in the above cases, their locations and directions of travel were not *dictated* solely by the bony features of the skull. This means that the exact path of every fracture cannot be predicted or explained.

Many of the fractures observed in the cases discussed here clearly exhibit the influence of strong and weak areas of the skull. For example, the tripod fractures seen in Cases 1, 3, and 4 are common fractures that reflect the relative strength of the malar eminence buttress and the weakness of the zygomaticotemporal and zygomaticofrontal sutures (17). Throughout the cases described above, the maxillae, sphenoid, nasals, zygomatics, frontal, parietals, temporals, and occipital exhibited fractures that were diastatic for all or part of their lengths. The anterior temporal buttress consists of a roughly teardrop or triangular shaped reinforcement just below the temporal line. On both sides of Case 3, fractures were observed that nearly outline this feature. It is likely that these fractures are occurring around the perimeter of this buttress, as opposed to through it, because of the greater resistance to fracturing posed by the stronger bone in the area. The fractures of the mastoid processes in Cases 1, 2, and 5 appear to lie just outside the inferior point of the posterior temporal buttress, while the buttresses of the nasofrontal process seem to have directed the oblique fractures of the maxillae in Cases 2 and 5. The vertical frontal fractures in Case 2 course through the weaker fossae on either side of the midline frontal buttress. Case 3 exhibits fractures that represent a combination of Le Fort II and Le Fort III fractures, while Case 2 exhibits fractures that represent a combination of Le Fort I and Le Fort II fractures. A Le Fort II pattern is present in Case 1, and Case 5 exhibits an incomplete Le Fort I fracture. Cases 1, 3, and 4 have fractures that involve foramina, most notably the foramen magnum in Case 1, both infra-orbital foramina, the right supra-orbital foramen, the incisive foramen, and the foramen magnum in Case 3, and the foramen magnum in Case 4. While the midline fractures of the frontal in Cases 1 and 3 run through the middle of a bony buttress, they began at an area of skeletal weakness near the nasofrontal suture (13,15) and frontal sinus (15), and extended superiorly, perpendicular to the inferior edge of the midfrontal buttress. The vertical fractures of the maxillae in Cases 1, 2, 3, and 4 run perpendicularly across the alveolar buttresses, not horizontally through them. This is consistent with general observations and expectations.

As these are hypothetical or theoretical ways in which to understand how skulls fracture, one cannot be certain that a specific buttress or system will visibly influence the fracture patterns of a particular case. In terms of the cases described here, the contributions of Rogers and Moritz more effectively explain the fractures that are present, while the systems proposed by Le Count and Gentry were less obviously applicable.

There are no attempts that we are aware of to discuss the location of fractures in the mandible in relation to theoretical buttresses. However, all of our cases with a blast origin near the mandible (Cases 1–4) exhibit the same fracture pattern, namely wedge-fractures of the chin (except Case 1) and vertical fractures of the mandibular body. Further, there are anatomical features that are consistent with the location of fractures seen here. For example, the mandibular eminence, trigone and torus are areas of bony thickness (45) that may translate into greater resistance to fracture propagation, thus influencing the path of fractures and giving rise to the repeated pattern of wedge-fractures in combination with vertical fractures. We believe that the wedge-fractures are created by "spalling off" or "blowing out" of the chin as a result of the outward expansion of the mandible in all directions due to the enormous pressure within the bony ring in concert with the specific skeletal features discussed above.

## Summary

This paper presents five cases in which a symmetrical craniofacial fracture pattern allowed forensic anthropologists to interpret the circumstances of death. The remains were found in association with a shotgun in two cases, a rifle in two cases, and a handgun in one case. The observed perimortem "suite of fractures" from each self-inflicted, midline gunshot wound is described and the bilateral symmetry of those fractures is discussed. Further, we suggest that some specific fractures may provide clues that the event in question was an intraoral or submandibular gunshot wound, including tripod fractures of the zygomatics, vertical fractures of the maxillae, vertical fractures of the mandible, a projectile path through the palate, wedge-fractures of the mandible, and symmetrical fracturing of the supraorbital region.

The application of buttresses, struts, and sutures in these cases has great explanatory value. Despite the fact that the strengths and weaknesses of the skull are features most often used in the analysis of blunt force trauma, their value in understanding other events, such as midline contact gunshot wounds, has been demonstrated here. This is an application with great importance, as nearly half of all suicidal gunshot wounds are midline contact wounds to the skull (18.8% intraoral, 15.6% frontal, 14.1% submandibular) (1).

The value of this paper lies in its ability to highlight features of cranial fractures that can be used to reconstruct individual death histories from skeletonized human remains. Even in cases where the skull is relatively incomplete, such as Case 4, the recovered bones and observed fractures can still provide clues as to what happened. Indeed, it is possible that the pattern seen in Case 4 would not have been recognized or would not have been understood if it were not for the striking similarities to Case 3. The significance of the fracture patterns described here lies in their applicability to other cases, which may be illuminated by a comparison within the interpretive framework of this paper.

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