RADIOLOGY CORNER

Keyhole Fracture of the Skull

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Note: This is the full text version of the radiology corner question published in the November 2008 issue, with the abbreviated answer in the December 2008 issue.

The authors present the case of a soldier wounded in Iraq with a gunshot wound to the skull exhibiting a characteristic keyhole fracture pattern on CT scan. Tangential gunshot wounds to the skull were termed "keyhole fractures" by Spitz in 1980 and the mechanics involved in the creation of the defect were later described by Dixon in 1982 (1,2). Keyhole fractures exhibit entrance and exit wound defects resulting from a projectile striking the cranium tangentially. The projectile's initial impact creates a circular entrance defect as the bullet strikes the outer table of bone and a secondary fracture is created by bone fragments propagated from the initial point of impact (2). External examination of the wound can therefore be confusing, manifesting signs of both entrance and exit type trauma (3). In triaging such wounds, it is useful for the examiner to be aware of the mechanics behind tangential gunshot wounds to quickly classify the type of injury and the associated trauma incurred by the patient. CT imaging is of particular importance in the medical work up of tangential gunshot wounds as it can show the keyhole fracture of the cranium as well as the lie of potential bone fragments within the calvarium. The following report reviews the presentation, role of imaging studies, and pathophysiology for keyhole fractures of the cranium.

Introduction

A keyhole fracture has a characteristic pattern which has previously been described as simultaneously exhibiting elements of both gunshot entrance and exit trauma. (3) Keyhole fractures can be created by bullets penetrating the skull at an angle, by a bullet yawing off path, or by grazing the skull at a tangential trajectory without penetrating into the intracranium (4,5). These fractures exhibit a circular entrance defect and a triangular exit defect created by bone or bullet fragments propagating from the initial point of impact on external examination or CT imaging (6). We present the case of a soldier wounded in Iraq with a gunshot wound to the skull exhibiting a characteristic keyhole pattern with resultant intracranial in driven bone fragmentation on CT.

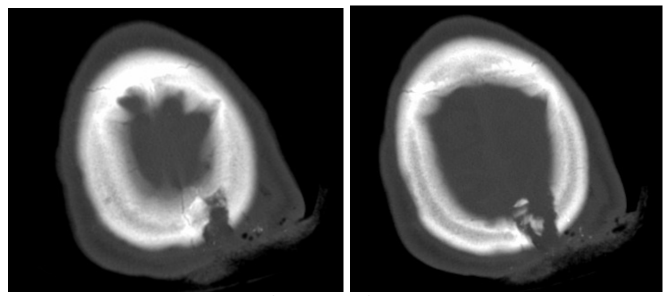

Fig. 1. Two superior slices of initial defect seen in bone windows showing keyhole defect.

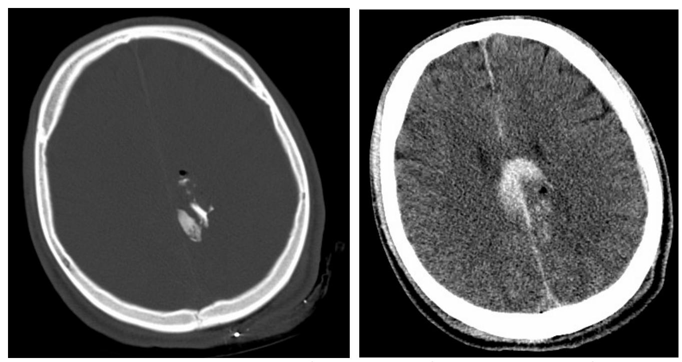

Fig. 2. Resultant trauma incurred from keyhole fracture. Note the far inward lie of bone fragments in (left image) and resultant trauma to the brain in (right image).

History

A 27 year old soldier in Iraq was flown from a forward operating base to the 332 EMDG (Expeditionary Medical Group) in Balad, Iraq after a reported gunshot wound to the head. The patient arrived awake, able to open eyes spontaneously, confused and disoriented, and able to obey commands (GCS E4V4M5) with right hemiparesis. Examination of the patient revealed a large stellate laceration of the left occiput with extruding brain matter. No other injuries were found. CT imaging of the head was obtained and showed a keyhole fracture with in driven bone fragments in the parafalcine region on the left with intraparenchymal hemorrhage and subacrachnoid hemorrhage, and no effacement of basal cisterns.

The neurosurgery team transported the patient urgently to the operating room and performed a debridement of the scalp,

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irrigation and drainage of the penetrating skull injury without craniotomy, and repair of the laceration via advancement flap

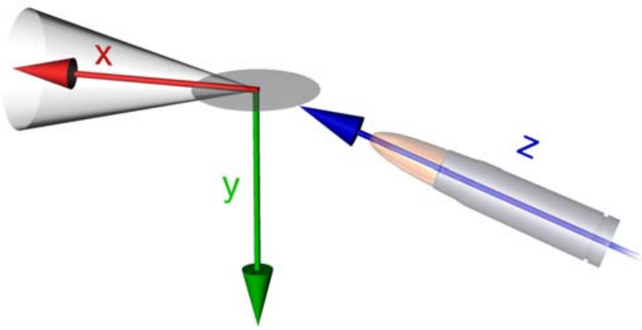

Fig. 3. Diagram of forces involved in creation of keyhole fracture. Arrow *Z* represents initial path of missile, arrow *Y* represents vertical force component, and arrow *X* represents horizontal force component. Shaded areas represent areas of boney defect.

of the left parieto-occipital scalp. Patient was alert, interactive, and following simple commands well when transferred to a higher echelon of care from Balad the following morning.

Summary of Imaging Findings

After immediate resuscitative efforts, an initial chest x-ray was obtained and negative for signs of trauma or other pathology. Initial head CT showed a keyhole defect high on the parietal bone on the left, impacted bone fragments in the parafalcine region (see figure 1) with some pneumocephalus, and a 3 x 3 x 2 cm high parietal subarachnoid hemorrhage and intraparenchymal hemorrhage (see figure 2). No effacement of the basal cisterns, intraventricular bleeding, or midline shift was noted. Helical CT scan performed the following day after debridement, irrigation, drainage, and closure of the gunshot wound showed that the bilateral high subarachnoid hemorrhage had decreased in size to 3 x 1.5 x 1 cm, intraparenchymal hemorrhage, no midline shift, cisterns present, and bony fragments stable.

Deployed radiologists during the time of our case used a standard penetrating head injury reporting format that allowed for expeditious preliminary reports while providing a simple and quick review for providers. The standard reporting format communicated the findings in a repeatable fashion for neurosurgeons and ER docs and ICU docs; knowing pertinent negatives were excluded (for example). (7)

Diagnosis:

Keyhole fracture of the skull.

Patient Discussion

A gunshot wound which strikes the cranium tangentially with enough force to penetrate the skull often produces a characteristic keyhole fracture pattern but can also be created by a bullet yawing off path or by grazing the skull at a tangential trajectory without penetrating into the intracranium (4,5). It is also interesting to note that keyhole fractures can also be created in tubular bones with tangential gunshot wounds by similar mechanisms (3). In gunshot wounds with a tangential trajectory to the skull, there are horizontal and vertical force vectors which govern the resultant trauma (2,3). See figure 3 for a graphic representation of the forces, figure 4 to show in more detail our case and the keyhole shape, and figure 5 for an external representation of the involved forces.

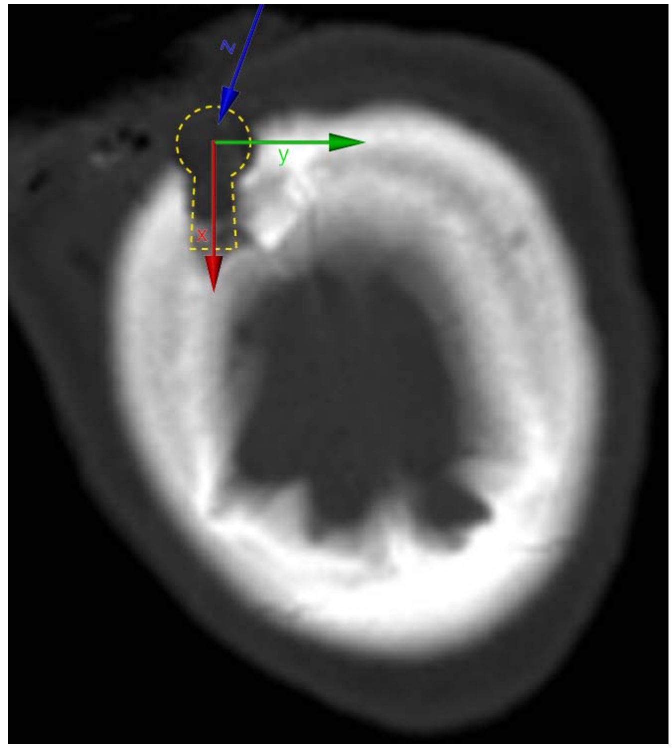

Fig. 4. Keyhole defect (arrow) better appreciated in this inverted slice shown in figure 1, with comparison drawing of keyhole on upper right.

The vertical force vector of the bullet striking the outer table of bone creates a circular defect and secondary fractures created by bone or bullet fragments propagate from the initial point of impact (2,3). This force can dislodge a segment of bone which is pressed upward as the bullet travels underneath (6). This dislodged wedge of bone represents the horizontal force vector of the bullet and is the means of the characteristic exit type feature keyhole fractures.

This type of injury may lead the examiner to believe that the intracranium was spared as it may appear like a superficial grazing injury. While the bullet and a portion of bone fragments may indeed exit along the initial path of the bullet, inward driven bone or bullet fragments from the vertical force component can create a fracture of the inner table of bone and possibly into the intracranium (2). The in-driven bone fragments can then travel within the calvarium in a characteristic pattern radiating out from the initial point of impact, such as in our case (5).

The fragmentation that occurs with keyhole fractures can be particularly destructive in nature- a fact which might be easily overlooked upon external examination of the wound. See figure 6 for a better understanding of the resultant fragmentation in our case. See figure 7 for a result of the SAH and potential brain swelling with sulci and fissural effacement.

To better understand the damage sustained within the calvarium in ballistic injuries, it is important to first understand the basic forces involved in ballistic trauma in soft tissue. In through and through (perforating) gunshot wounds, soft tissue is displaced in the path of the bullet, leaving behind a permanent cavity (8). A second pressure wave following the path of the bullet creates a temporary cavity, which displaces surrounding tissue on a scale determined by the tissue's elasticity and compliance (8). Furthermore, bone or bullet fragments radiating out from the path of a bullet after the time of impact weaken the surrounding tissues allowing cavitation and fragmentation to work synergistically to increase cavity dimensions and destruction in the path of the bullet (8). Inward driven chips of bone or missile fragments can each result in damage as significant as that incurred by a true through and through injury of soft tissue (5).

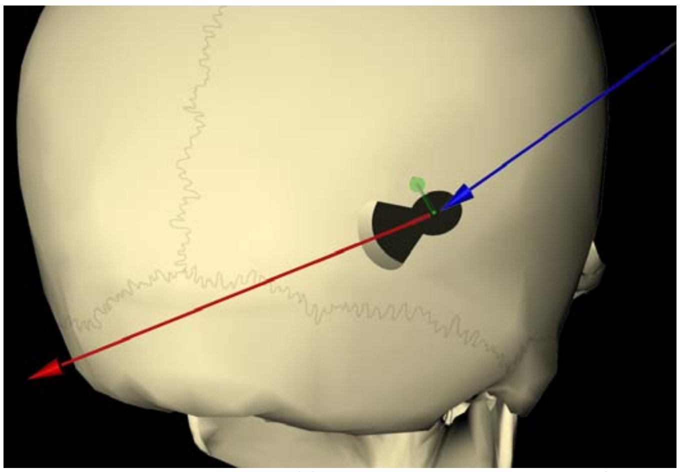

Fig. 5. External representation of force vectors involved in keyhole fracture. Note the beveling of the "exit" component. Also note the shaded green arrow representing the force vector for the in-driven fragments.

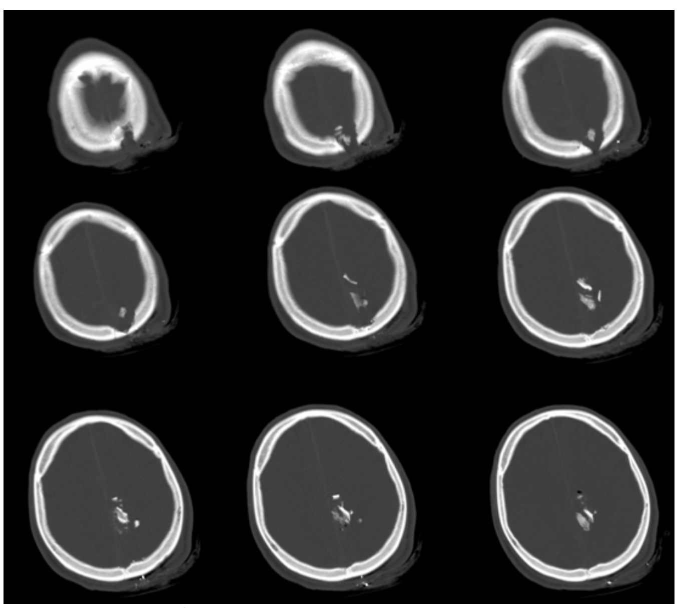

Fig. 6. Resultant fragments shown on sequential bone window CT axial scans.

Injuries to the calvarium differ significantly from those involving soft tissues in other sites of the body. Jandial et al. reviewed the relation of ballistic injury and cavity formation in the closed pressure, closed volume system of the cranium (5).

Fig. 7. Interhemispheric and right parieto-occipital fissure SAH associated with the bone fragments, just inferior to the keyhole fracture. Note also the relative swelling of the left hemisphere indicated indirectly by absence of the cingulate, pre and postcentral sulci and left parieto-occipital fissure.

Jandial et al. argue that the damage incurred by cavity formation from ballistic injury involving the cranium is as significant, if not greater, than in other areas of the body. Due to the cranium being a closed pressure and volume system, the radial distribution of forces creating cavity expansion found in other tissues is restricted (5). This restriction does not decrease the amount of trauma, but rather causes curvilinear displacement of the cavity forming forces on the tissue with significant strain on brain matter, which is less compliant than most soft tissue found elsewhere in the body (5). The shearing force of the volume restricted cavitating energy coupled with bone fragments serving as secondary missiles and surrounding tissue softeners make damage caused subsequent to keyhole fractures potentially devastating in nature and in excess of what one might assume from external visualization of the entrance wound (5,8).

It should be kept in mind that the keyhole pattern may contribute to incident analysis during firefights in combat overseas or even in multiple victim sniper attacks stateside. (9,10). Because the direction of missile can be determined based on the pattern dynamics, this can support direction of the gunshot at the scene, when compared to patient position and other casualties wound patterns during the incident.

Summary

Keyhole fractures, while rare, represent an entity deserving of contemplation when triaging gunshot wounds to the skull. With consideration of the patient's clinical condition and knowledge of potential atypical presentations associated with gunshot trauma to the skull, the triaging physician can quickly and accurately evaluate for central nervous system injury and plan care accordingly. Furthermore, the discrepancy between observed and actual craniocerebral trauma in keyhole fractures stresses the importance of radiographic imaging in gunshot wounds to the skull in determining the extent of damage as well as the lie of any inward driven bone fragments or debris in the wound. Lastly, incident analysis may be complemented from known wound patterns and ballistics such as presented here and in related cases.

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