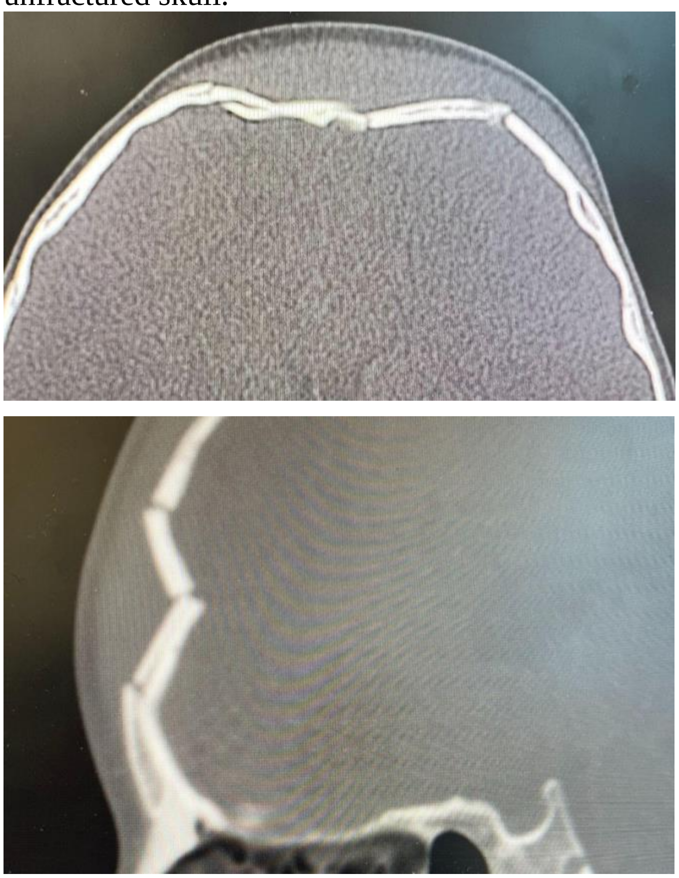
Elevation of Depressed Skull Fracture

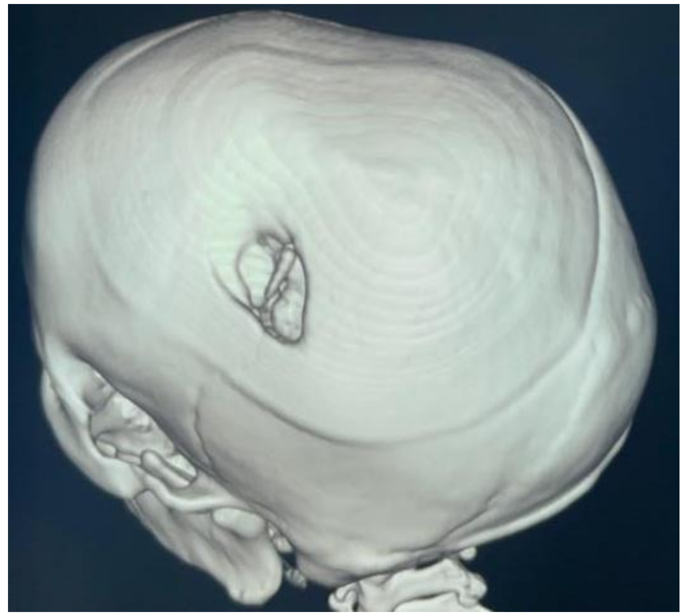
Megan E. H. Still, Joseline Haizel-Cobbina, Dickson Bandoh, Peter Waweru, Michael C. Dewan

Introduction:

Skull fractures typically result from high energy injuries and can be linear, depressed, "ping-pong" (typically in the pediatric population), or, in rare circumstances, elevated. Approximately 7.59 million people worldwide experienced a documented skull fracture in 2019, with an incidence of approximately 98.9 per 100,000 population annually. Depressed skull fractures are fractures of the cranial vault in which the edges of the bone fragments are displaced from one another and one fragment is depressed into the intracranial space, altering the natural curvature of the calvarium. A skull fracture is not considered significantly depressed unless the fragment is displaced at least the width of the bone. This condition can be seen on imaging when the outer table of the depressed fragment is in line with, or deeper than, the inner table of the adjacent unfractured skull.



Axial (Top) and sagittal (Bottom) CT scan demonstrating a depressed frontal bone fracture. This is "Patient 1" in the text below.



3-dimensional CT scan reconstructed image of a circular depressed skull fracture. This is "Patient 2" in the text below.

<u>Causes and Mechanisms</u>

Although global data on incidence and mechanism of injury are currently lacking, regional studies agree that the most common mechanism of skull fracture is road traffic accident followed by falls or assault in some contexts.

The majority of depressed skull fractures occur in the frontotemporal regions. They can be associated with additional intracranial injuries such as epidural or subdural hematomas, parenchymal contusions, or dural lacerations. Open depressed skull fractures have a higher risk of infection than other traumatic brain injuries, because of the risk of dural tear and cerebrospinal fluid leak due to displaced fragments. Open depressed skull fractures also have a higher risk of seizure, neurologic deficits, and death.

<u>Clinical assessment and diagnosis</u>

Primary trauma assessment must always be performed first, involving evaluation of airway, breathing, and circulation (ABCs) to ensure the patient is not at imminent risk and is stable for neurologic examination and imaging.

The presenting signs and symptoms of depressed skull fractures are as varied as in traumatic brain injury, ranging from neurologically intact to

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comatose, depending on the extent of intracranial injury and polytrauma. A full neurologic examination should be performed, focusing on Glasgow Coma Scale / alertness and any motor or sensory deficits that may be secondary to injury caused by depressed skull fragments or related intracranial trauma. In cases of severe trauma or evidence of herniation syndrome (altered consciousness accompanied by a unilateral fixed and dilated pupil and/or hemiparesis), always remember to perform an abbreviated neurologic examination for injury localization before you intubate a patient.

In severe cases, a depressed skull fracture may be diagnosed by simple inspection of the head, particularly in those with severe cosmetic defects or an open laceration over the fracture. A CT scan of the head is the gold-standard for diagnosing skull fractures and is helpful in evaluating accompanying intracranial injury. If a CT scan is not available, a skull X-ray can diagnose the bony injury, though it will not assist in evaluation of accompanying parenchymal injury.

Management/ Treatment

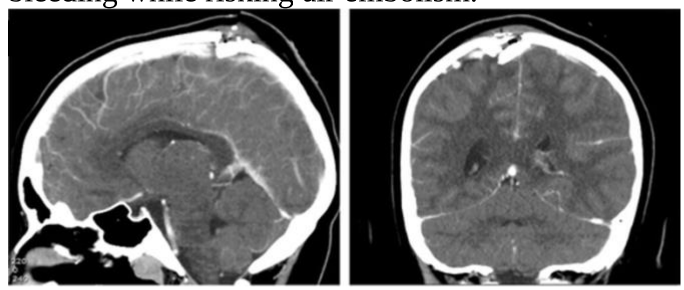
As with any traumatic injury, initial stabilization of the patient, including ABCs and a thorough primary and secondary exam, must be undertaken prior to management of depressed skull fracture.

Indications for surgical management of depressed skull fracture include the following:

- Depression that is greater than 5-10 mm. Often a good "rule of thumb" is that surgery is indicated if the outer table of the depressed edge is below the inner table of the corresponding edge.
- Dural tears that require repair to prevent cerebrospinal fluid leak
- Involvement of the frontal sinus, especially if there is severe comminution.
- Significant pneumocephalus or intracranial hemorrhage, particularly in the context of neurologic deficits.

Consider also significant or bothersome cosmetic deformities. Many depressed skull fractures can be managed nonoperatively, particularly in the setting of minimal depressed state, closed injury, absence of intracranial hematoma, and reassuring neurologic exam.

Additionally, extreme caution should be taken before surgically addressing a depressed skull fracture adjacent to large venous structures such as the superior sagittal or transverse sinuses. Even simple fracture repair can be met with torrential bleeding while risking air embolism.

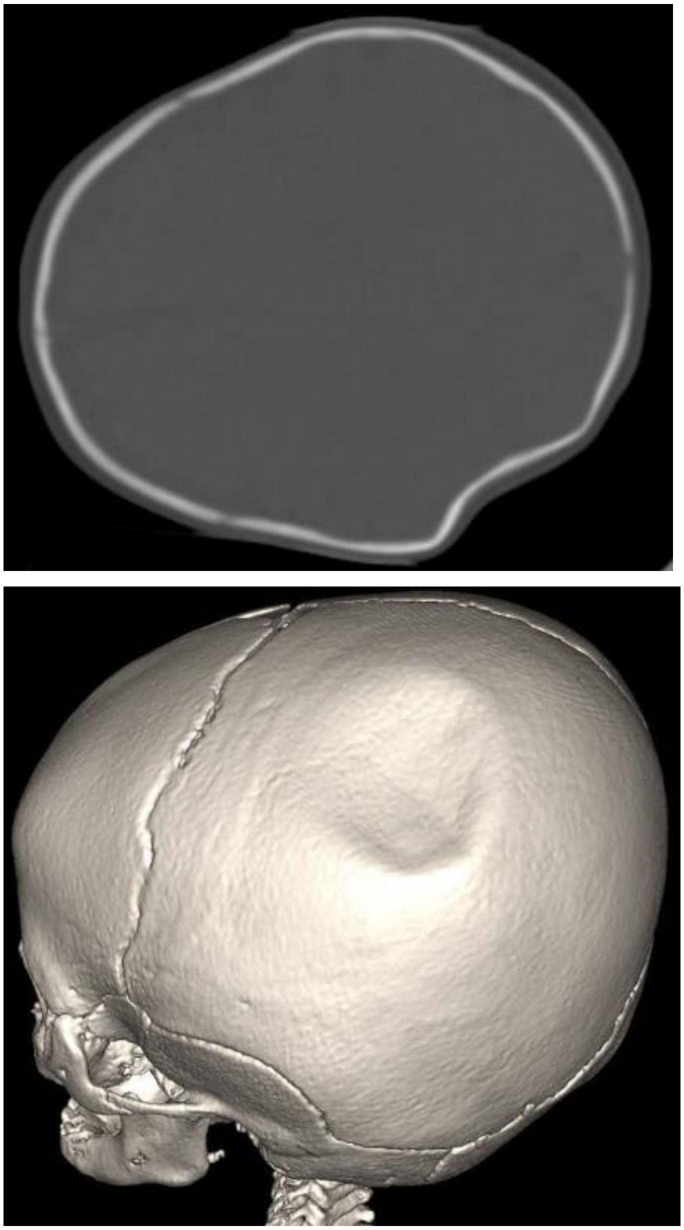


Sagittal (Left) and coronal (Right) views of a depressed skull fracture that likely perforates the sagittal sinus, which runs at the midline along the interhemispheric fissure. When such cases are over the motor cortex, they can present with weakness of the leg or foot, making management decisions more difficult. Source: https://doi.org/10.1007/s00381-017-3485-z

In the case of a minimally depressed skull fracture in a neurologically well patient with an open laceration over the fracture, conservative management may still be considered. The laceration should be thoroughly irrigated with several liters of sterile water or saline to wash out debris, then scrubbed with a chlorhexidine or other scrubbing agent, prior to multilayer incision closure, preferably with non-braided monofilament suture to reduce risk of infection. Though it is debated, a short course of prophylactic antibiotics may be considered for those who had conservative management of an open, minimally displaced fracture.

A minority of depressed skull fractures present as "ping-pong" type in the pediatric population. This subtype of fracture has no fragments, but results from depression of a portion of an infant's still thin and relatively pliable skull, in a smooth, bowl-like shape into the intracranial space. Non-surgical management options for ping-pong fractures such as vacuum assisted pumps have been successful in restoring skull contour in an ICU setting without the need for anesthesia. Most of such fractures - particularly when depressed less than

5mm - can be managed conservatively with routine follow up.



Axial (Top) and 3D reconstructed CT scan of ping-pong type fracture (Cases courtesy of Drs. Y. Glick and M. Mohamed, https://radiopaedia.org/articles/ping-pong-skull-fracture?lang=us)

Preoperative considerations

After initial trauma evaluation, a discussion with the anesthesia team is essential to ensure safe preparation prior to surgical intervention. Timing of and methods of intubation may be affected by changes in neurologic status, airway compromise from polytrauma, or maxillofacial trauma. See Airway Management in Trauma. Despite the urgent nature of intervention for many significant traumatic brain injuries, a minimum of a primary trauma survey and basic blood work such as hemoglobin, platelet count, and coagulation factors should be completed prior to surgery to guide management. The need for blood transfusion can also be heralded by radiographic or physical exam findings such as swirl sign indicating possible active intracranial bleeding, pulsatile scalp bleeding, or fracture depression of subjacent venous sinuses.

Elevation and repair of depressed skull fracture proceeds in the following steps:

- Planning and communication with anesthesia and other providers
- Clip hair, prepare and drape
- Incision and exposure of the fracture
- Burr holes and craniotomy around the fracture
- Inspection and repair of the dura if necessary, and any other intracranial interventions such as hematoma evacuation
- Reduction and fixation of the fracture
- Placement and securing the bone flap in place
- Scalp closure

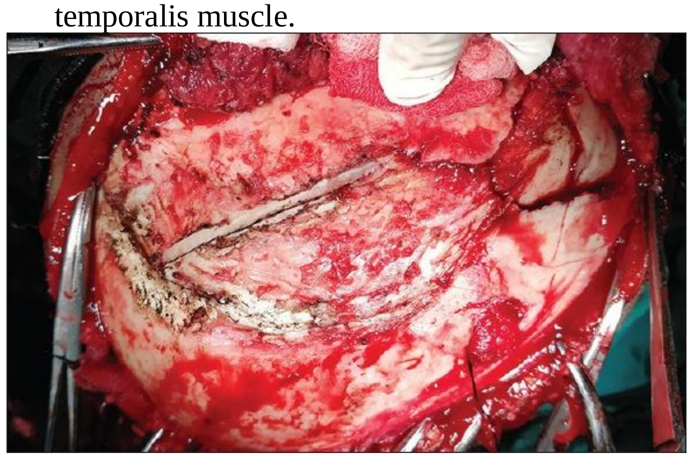
Steps:

1. At least two functioning intravenous lines should be placed and available for access by the anesthesia team. If feasible, an arterial line allows for close hemodynamic monitoring. Placement of a central line may be considered if there is concern for hemodynamic instability or a high risk for sinus injury or a venous embolism, as described above.
2. Communication with the Outpatient or Casualty departments and Anesthesia teams should be ongoing during surgical planning. A complete review of the above considerations should be repeated with the anesthesia and operative staff during a pre-incision time-out.
3. Repair of a depressed skull fracture typically does not require significant specialized equipment or technology. Typical cranial operative equipment such as drills, monopolar and bipolar cautery to control bleeding, force-

control suction tips, and theater lights and/or headlights can be sufficient for a safe and effective surgery. In an ideal situation, a high-speed drill with a craniotome and a footplate would be available for rapid and safe placement of burr holes and creation of a craniotomy flap. Hemostatic agents such as bone wax, cottonoid patties and gelfoam are ideally available to the surgeon. See Lateral Craniotomy for more details.

4. Additional equipment preparations should be made based on pattern of injury and expected potential complications: Depending on the extent of parenchymal injury and additional traumatic brain injuries, a ventriculostomy drain may be required for ventricular decompression with a herniating brain or for intracranial pressure monitoring. An intraoperative ultrasound can be useful in many contexts, including to evaluate for intracranial hemorrhage, look for subdural hematoma to determine if an intact dura needs opening, or to guide ventriculostomy drain placement, if indicated.
5. Positioning should be done such that the depressed skull is exposed, with enough room to extend around the fractured pieces if a craniotomy is planned. Typically, it is best if most of the depressed fracture is at the apex of the head, though consideration should also be taken for intracranial injuries, such as subdural hematomas, that may need to be accessed.

   Cranial fixation can be accomplished in several ways, depending on location of injury, age of patient, and access to resources. Pinning the head in a Mayfield cranial fixation may be considered in some circumstances; however, a safe craniotomy can be performed with the head resting securely on a horseshoe head frame, particularly for a simple pterional approach, and allows for positioning in the supine, prone, and lateral positions. If a Mayfield or horseshoe headrest is not available, cranial fixation may be accomplished with a combination of bumping and propping with pillows, blankets, or bumps +/- tape. As with any surgical procedure, assure that all of the patient's body is secured in as neutral a position as possible, taking care to pad potential pressure points and avoid nerve impingement, particularly at the axilla and hips. A dynamic bed allows intraoperative patient manipulation; Trendelenburg and reverse Trendelenburg positions can assist with surgical exposure and safety.
6. Give the patient a generous haircut with electric clippers to mitigate infectious risk and a wide exposure. Be sure to allow for extension of the initial incision if you decide this is necessary during the procedure.
7. The type of incision will be guided by fracture location and exposure needed to repair the defect. If the fracture is small and only a fragment needs elevation, a simple linear incision over the fracture site is often adequate. For more extensive fractures or for patients who require additional intracranial interventions such as subdural or intracranial hemorrhage evacuation or frontal sinus exenteration, a more extensive incision may be more appropriate, including a full "reverse question mark" trauma flap incision or a bicoronal incision that extends over the top of the head from approximately 1 cm anterior to the tragus bilaterally. The entirety of the bony injury should be exposed with the incision, often requiring elevation and inferior reflection of the temporalis muscle.



The scalp incision and flap should be adequate to expose all of the skull fracture. Source: https://doi.org/10.4103%2Fajns.AJNS_111_19

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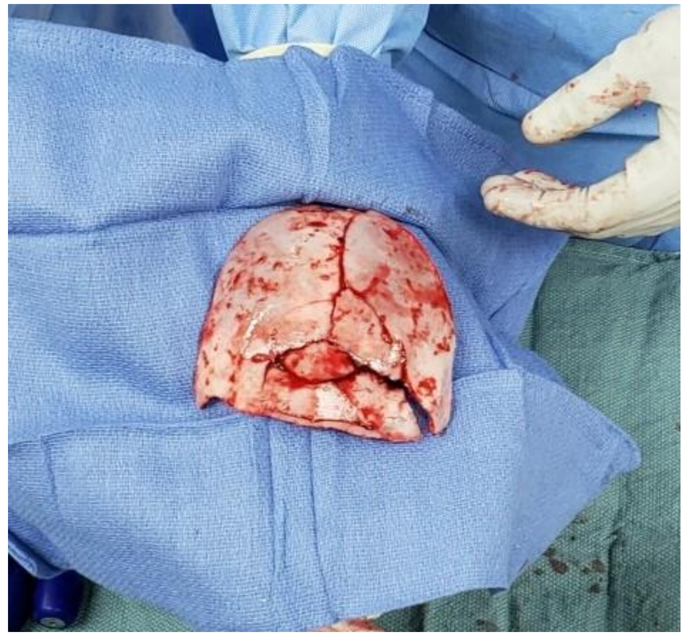
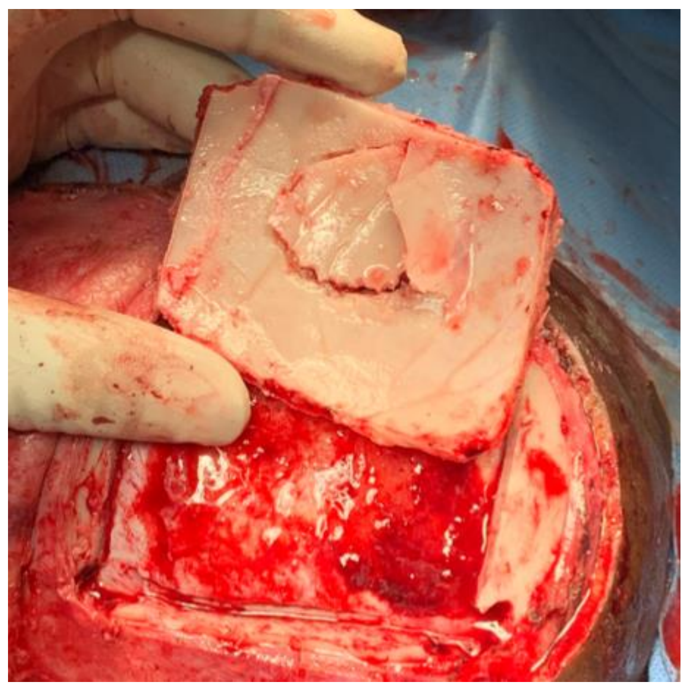
Frontal skull fracture- the best incision in this case was a bicoronal craniotomy that exposed all of the frontal bones from the vertex of the skull (bottom of picture) to the upper orbits (top of picture.) Source: https://doi.org/10.1155%2F2014%2F879286

8. Burr holes should be thoughtfully placed away from the fracture line but to allow for adequate bony elevation. Burr holes may be made with a perforator or manually with a matchstick drill bit, based on surgeon preference and indications for speed (such as active herniation or uncontrolled bleeding). If these tools are not available, manual burr hole drills and a Gigli saw may be used to create a craniotomy around the fractured fragments.
9. For a simple linear depressed skull fracture, the depressed edges may be elevated directly and plated together for stabilization. Burr holes may be drilled to assist in elevation of the depressed edges or to elevate the depressed portion of a "ping-pong" fracture.
10. For larger, more complex, or multi-fragment fractures, drill a craniotomy circumferentially around the fragments by connecting the burr holes with the cutting bit of an electric perforator, or with a Gigli saw.



Circumferential craniotomy around all bony fragments involved in the fracture allows the fracture to be elevated safely away from the dura and brain, rather than risking damage by trying to elevate the fragments while they are adjacent to the brain (Patient 1).



Circumferential craniotomy around the circular depressed fracture, once again avoiding manipulation of sharp bone fragments while they are in contact with the dura or brain (Patient 2).

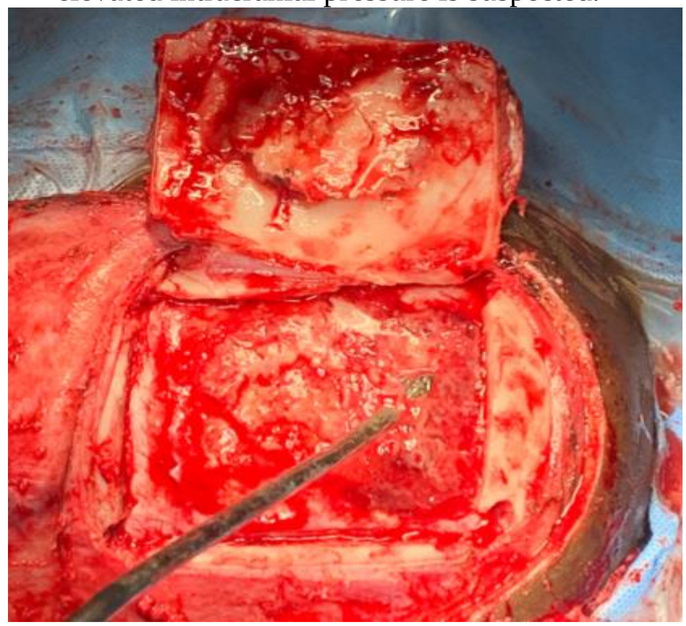
11. In cases of severe fragmentation or fragment loss, a craniectomy may be performed and the bone

flap is removed. The defect is filled with titanium mesh, split graft donor bone, or allographic implant, depending on the situation. In resource-limited settings, the defect may remain in place until a later date.

The degree of bony work should also be guided by the need for intracranial exploration: if there is no evidence of intracranial hemorrhage or dural laceration, simple elevation of the fracture may be an option. Craniotomy or craniectomy may be required for evacuation of a subdural or intraparenchymal hemorrhage or for dural defect repair, if indicated. During bony elevation, it is important to carefully dissect dura from the underside of the calvarium to avoid inadvertent dural tears during exposure.

The craniotomy flap should be carefully elevated off the dura, keeping in mind that the dura is often adherent to the bone or contiguous with the inner table periosteum. Care should be taken to scrape the periosteum/dural layer off the bone prior to elevation to avoid causing a durotomy.

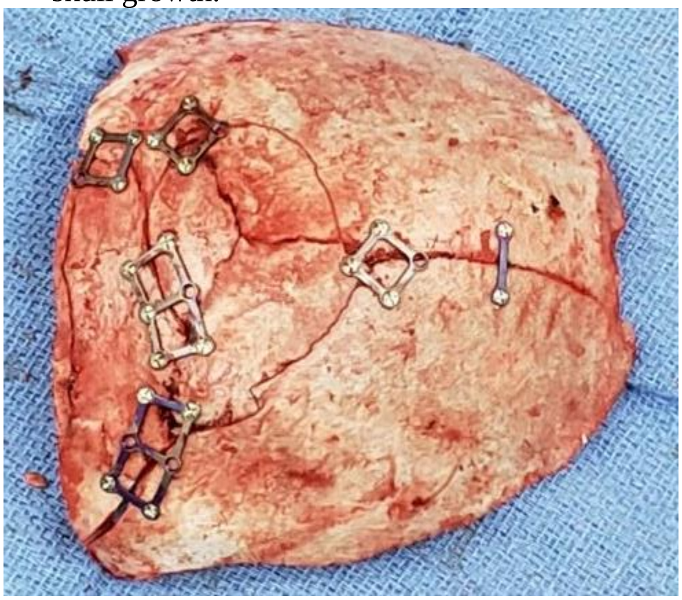
12. After the bony fragments are removed from the field, the dura should be thoroughly inspected for defects or signs of intraparenchymal injury. Evaluate for bleeding dural vessels that can contribute to epidural hematomas, and purplish discoloration which can indicate subdural hematoma. Touch the dura gently to assess its tenseness, to get a feel for blood under pressure or elevated intracranial pressure. Intraoperative ultrasound can be helpful in evaluating for intraparenchymal hemorrhages if preoperative imaging was equivocal or if dura is more tense than expected. Dura should be opened, in a cruciate or stellate fashion, for evacuation of subdural or intraparenchymal hemorrhages or if elevated intracranial pressure is suspected.



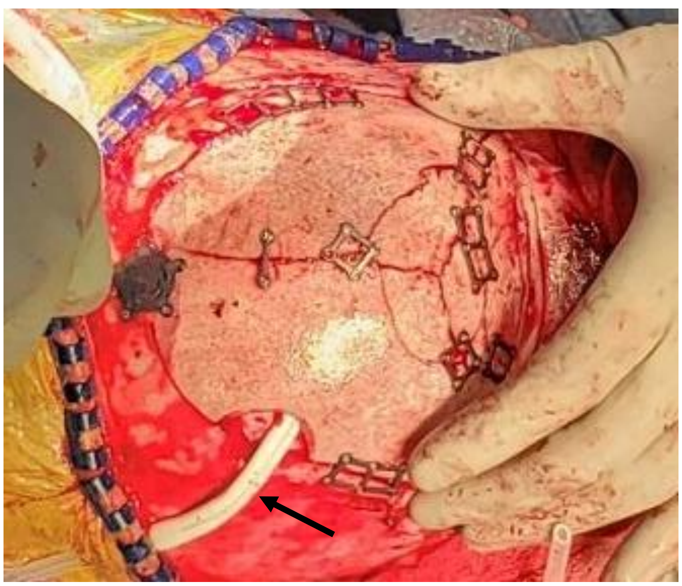
Visual and tactile inspection of dura. There does not appear to be a dural defect or underlying hematoma in this case

13. If the dura is opened, a similar visual and tactile evaluation should be performed of the parenchyma, paying special attention to bleeding cortical vessels and the pulsatility of the parenchyma. If the parenchyma herniates through the bony defect quickly, it may be necessary to extend the craniotomy, perform a partial lobectomy if parenchyma is non-viable, or plan for a craniectomy to accommodate the elevated intracranial pressure.
14. The approach to dura closure depends on the severity of injury. For patients with minimal intracranial injury or simple subdural hematoma evacuations without extracranial herniation, the dura may be laid over the parenchyma or closed with suture via loose approximation. A water-tight closure is typically not necessary unless exposure includes the posterior fossa. Small dural lacerations with no evidence of intracranial injury can be repaired primarily without subdural exploration.
15. Fixation of the bone fragments or flap may be accomplished with cranial fixation plates or with

sutures if plates are not available. In resource-rich settings, in the pediatric population dissolvable plates or sutures are recommended for patients under 3 years of age to accommodate skull growth.

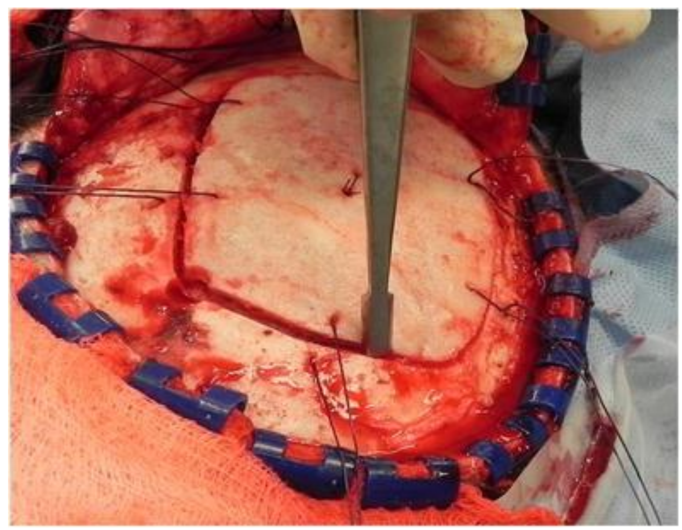


Bone fragments are secured together using cranial fixation plates



The reconstructed bone flap is affixed to the native calvarium. The burr hole defect was utilized for epidural drain placement (Black arrow).

Bone fragments may be affixed to the periosteum native calvarium with sutures if cranial fixation plates are not available



Multiple holes can be drilled in the native calvarium to secure the bone flap with suture. Source: https://doi.org/10.1007/s00381-017-3620-x

Care should be taken to maintain the bony contour as much as possible by including all large fragments. Adding a slight bend to fixation plates can also improve contour and decrease the risk of skin dehiscence due to protruding foreign bodies. The reconstructed flap should then be fixed to the adjacent skull.

16. In the setting of severe brain injury, suspected elevated intracranial pressure, or overt

parenchymal herniation intraoperatively, a craniectomy may be chosen, leaving the bone flap off prior to closure. In these instances, best judgment should be used in deciding whether to keep or discard the elevated flap. If the fracture was open with significant dirt and debris or if there are several small fragments, the flap may be discarded with future plans to replace it. This option may reduce the risk of infection after cranioplasty if the fracture was open and overtly contaminated and may result in better cranioplasty contour if the fracture was heavily fragmented. Alternatively, if the fracture was not open or fragmented, common practice is to save the elevated bone flap for future replacement, either in a designated tissue fridge if available or in the subcutaneous space in the abdomen if it is not. These decisions are more complicated in resource-limited settings, where alloplastic materials such as bone cement and titanium mesh are often not available.

17. To preserve the bone flap in the abdomen, an incision can be made on the abdomen and dissection performed to create a space just superficial to the fascia of the abdominal wall. After placing the bone in this new subcutaneous cavity, the incision can be closed in layers. If the patient has a severe brain injury, take care to place the flap such that it would not interfere with the placement of a feeding gastrostomy tube.
18. Closure type should be guided by patient age and concerns for secondary brain injury. An external ventricular drain may be left if there is concern for cerebral injury or edema, either based on the presenting neurologic exam, pre-operative imaging findings, or intraoperative behavior of the parenchyma. Intraoperatively, ventricular drains can be placed based on anatomic landmarks or with imaging guidance such as ultrasound or stereotactic navigation. Consider whether the patient needs postoperative intracranial pressure monitoring. We recommend placing a monitoring device (fiberoptic wire or ventricular drain) in the following situations: preoperative Glasgow Coma Scale of 8 or less, full or tight brain encountered during fracture elevation, radiographic evidence of cerebral edema, or anticipated additional operations needed to address polytrauma injury.
19. Gentle suction drains such as Jackson-Pratt drains may be placed during closure, either subdural or subgaleal, depending on the extent of opening. If a subdural hematoma was evacuated, many advocate placing a drain to mitigate the risk of hematoma re-accumulation; this topic remains debated. In a low-resource setting, a soft latex drain such as a 12F Foley catheter with extra holes cut in it, attached to gravity drainage, is an acceptable alternative.
20. Skin closure materials can be chosen based on incision location, surgeon preference, and available materials. A multi-layered approach should be undertaken with simple interrupted dissolvable suture used to close temporalis fascia, inverted dissolvable suture used to close galea, and a final dermal closure. Skin staples are a common choice for dermal closure provided the galea is closed separately. Non-absorbable suture such as monofilament nylon is also a good option to prevent bacterial growth on braided suture and allows for inspection of the incision prior to suture removal. Dissolvable suture is sometimes considered in the pediatric patient if intracranial trauma was minimal with minimal parenchymal swelling and no plan for re-operation (e.g. no need for cranioplasty at a later date).
21. Patients who undergo surgical intervention for depressed skull fracture should be monitored in an intensive care unit in the immediate postoperative period. For those with ventricular drains or pressure monitors, intensive care is a requirement. Every 1–2-hour neurologic examinations should be performed by neurologically trained staff, and the surgeon informed immediately of signs of decline in neurologic status. Close monitoring of fluid status and vital signs is important to maintain appropriate intracranial and cerebral perfusion pressures. While ventricular drains should be monitored hourly for intracranial pressure trends and output, subdural or subgaleal drains can be evaluated and output measured every 4-6 hours.

The surgical team should be notified promptly of any acute changes to drain output.

22. After initial surgical intervention, the primary focus turns to prevention of secondary injuries. For patients with severe traumatic brain injury, trauma guidelines recommend a 7 day course of prophylactic antiepileptic medication, which can help prevent early post-traumatic seizures, though it does not improve long-term outcome. Some surgeons chose to prescribe a week of prophylactic antiepileptics to patients with moderate traumatic brain injury who underwent surgical intervention or were found to have intracranial hemorrhage. In addition to maintaining appropriate intracranial and perfusion pressure levels and fluid management, care should be taken when positioning patients, especially those who are comatose or experiencing motor deficits. Pressure points such as sacrum, hips, elbows, and heels should be padded, and a regular regimen of turning should be instituted to avoid pressure wounds. Special care should be taken to avoid pressure wounds on the posterior of the skull, particularly if the area has traumatic lacerations or abrasions. Finally, wound care should be tailored to the incision location, closure material, and context. A simple bandage may be used as barrier protection for the first 24-48 hours postoperatively, after which the incision may be left to air if the context is sufficiently clean. Care should be taken to keep the incision clean, dry, and not covered by hair, hats, or scarfs, until it is fully healed.
23. Follow up times will vary depending on extent of injury and intervention, length of intensive care and hospital stay, and extent of persistent neurologic deficit. At a minimum, a patient should be evaluated approximately 10-14 days after surgery to ensure the incision is healing appropriately and there are no signs of early infection. A postoperative CT scan is often not necessary in the case of a simple skull fracture repair but may be desired to evaluate for ongoing resolution of intraparenchymal or subdural hematomas, particularly for those who are not neurologically intact.

Outcomes:

An isolated skull fracture typically presents with minimal symptoms or symptoms of concussion and has a good prognosis for recovery after surgical repair. Prognosis after depressed skull fracture is largely related to additional intracranial injuries and/or complications encountered intraoperatively. In many studies, most patients had good long-term outcomes after a brain injury with a depressed skull fracture; however, this is certainly influenced by the extent of parenchymal damage and secondary brain injury. Motor deficits, pneumocephalus on admission CT scan, pre-operative GCS<13, need for reoperation, and hospitalization longer than 3 days were found to be predictors of poor neurologic outcomes in one study. Persistent neurologic deficits may necessitate long-term physical therapy or a stay in an inpatient rehabilitation center during the recovery process. In resource-poor settings, long-term rehabilitation by professionals is out of reach of most families, who find that the burden of care falls on them. Discussions around these situations can be very difficult and should be led by a member of the team who understands the needs and abilities of families in the local context.

In addition to the outcomes related to brain injury, patients who undergo surgical repair of depressed skull fracture are at risk for postoperative infection (reported in 4-16% in some case reports), seizures (3-12%), and cerebrospinal fluid leak (3%).

Pitfalls

Fractures traversing the venous sinuses have unique risks. It is recommended to get a CT venogram, MRA or angiogram with venous flow phase for adequate evaluation. If these are not available, a knowledge of venous sinus anatomy as it relates to the fracture pattern is crucial. After evaluation, the decision to operate on these patients is based on the degree of venous flow compromise, location of the sinus involvement and the neurological status of the patients. Midline fractures over the “motor cortex” and sagittal sinus may present with ipsilateral or bilateral lower extremity weakness due to impingement of the fracture on that portion of the "homunculus."

Neurologically stable patients with a closed fracture over a patent venous sinus can be observed. If the fracture is open, the patients should undergo debridement without elevation of the bone segment. However, neurologically unstable patients or those with severe deformity may require urgent elevation of the depressed bone segment. In this case, special preparations should be made in case of violating the sinus, including sinus paddies (comprised of surgicell and a pledget) to hold gentle pressure, suture to repair defects, and type and crossmatched blood available or in the room for transfusion if massive bleeding is encountered. Violation of the sinus also significantly increases the risk of an air embolism, so close communication with the anesthesiology team must be maintained: Notify the anesthesiologists if the sinus is entered and ensure continued monitoring of end tidal pCO2. If air embolism is suspected, rapidly flood the field with saline, turn the patient or bed such that the left side is down, and move the patient to the Trendelenburg position.

Conclusion:

Depressed skull fractures comprise a variety of injuries and can present as simply as a cosmetic deformity in an intact patient or accompany a severe traumatic brain injury. Considerations for operative management include whether the fracture is open or there is exposed bone, the significance of the displaced fragments, the patient's neurologic status and severity of polytrauma, and suspicion or confirmation of additional intracranial injuries. The goal of surgical management includes elevation of the fractured bone fragments, evaluation and evacuation of possible subdural injuries, evaluation and repair of dural defects, and reconstruction of the normal round contour of the skull. Specific approaches to treatment and follow up will depend on severity of injury and resources available in each context.

Megan E. H. Still, MD
University of Florida
Florida, USA

Joseline Haizel-Cobbina, MBChB, MPH
Vanderbilt University Medical Center,
Tennessee, USA

Dickson Bandoh, MBChB, FWACS
Komfo Anokye Teaching Hospital
Kumasi, Ghana

Peter Waweru, MBChB
Tenwek Hospital
Kenya

Michael C. Dewan, MD, MSCI
Vanderbilt University Medical Center,
Tennessee, USA

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