Medical Management of Elevated Intracranial Pressure

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Case Presentation

A 24-year-old man fell approximately 30 feet while working as a roofer; he had a loss of consciousness following the impact but regained consciousness and was agitated and able to protect his airway during transport via EMS to a level one trauma center.

On arrival, his exam had deteriorated, and he arrived with a Glasgow Coma Scale (GCS) score of 6T. He was intubated on arrival in the emergency department trauma bay. His initial exam demonstrated multiple facial and scalp lacerations and abrasions, along with ecchymosis and edema surrounding the right orbit requiring lateral canthotomy. His pupils were 4 mm and sluggish bilaterally, he had cough and gag reflexes and a left corneal reflex; he withdrew all extremities to pain.

Questions

1. What is the most likely diagnosis?
2. What imaging should be obtained emergently?
3. What imaging should be obtained in a nonurgent fashion?

Assessment and Planning

Given the nature of his injury, the presence of multiple lacerations and ecchymoses, and the poor neurological exam, a significant intracranial hemorrhage was suspected. The patient was taken for an emergent noncontrast CT of the head and cervical spine. Additional trauma scans of the chest, abdomen, and pelvis with reconstructions of the thoracolumbar spine were also obtained as part of the trauma protocol.

The head CT demonstrated multiple facial fractures, a nondisplaced linear skull fracture, frontal sinus fracture, left side subdural hemorrhage, bilateral frontal intraparenchymal contusions, and subarachnoid hemorrhage (Figure 1.1).

A CT angiogram (CTA) of the head and neck was obtained during the same scanning period because the patient remained hemodynamically stable. The scan showed no evidence of aneurysm, dissection, or vascular malformation.

In cases where the patient's exam is out of proportion to the extent of intracranial injury seen on head CT, a noncontrast MRI brain may provide additional information, particularly regarding diffuse axonal injury (DAI), that clarifies prognosis and may

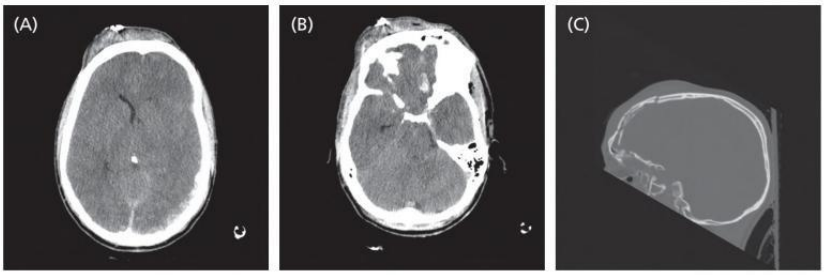

Figure 1.1 (A) Anteroposterior plain skull film, and (B&C) Axial CT brain showing left occipital skull fracture extending down to suboccipital bone.

inform family discussions and treatment planning. However, MRI is not recommended as an emergent imaging modality.

Questions

1. How do these radiographic findings influence the treatment plan?
2. What interventions should be performed immediately for this patient?
3. What additional interventions may be considered prior to surgical intervention?

Oral Boards Review: Diagnostic Pearls

- On plain head CT, thoroughly assess bone, parenchyma, and ventricles for pathology.
  - Mass lesions, midline shift, displaced or comminuted skull fractures are reason to consider immediate operative management.
- All suspicious lesions, particularly in young patients, should have additional vascular imaging obtained.
  - CTA head and neck can assess for arteriovenous malformation (AVM), aneurysm, and dissections.
  - MR angiogram is not useful as an emergent study in an unstable patient.
- In patients with an exam out of proportion to injury on head CT:
  - Consider an MRI when able to assess for DAI.
  - Imaging of the craniocervical junction, cervical spine, and thoracolumbar spine may uncover other causes for a poor exam.

Decision Making

Although his imaging demonstrated multicompartment hemorrhages, there was no significant midline shift or evidence of mass effect. Therefore plans were made for medical management of his injuries. The patient was admitted to the neurosurgical intensive care unit (NICU). The Brain Trauma Foundation (BTF) guidelines previously recommended

intracranial pressure (ICP) monitoring in patients with GCS of less than 8 and an abnormal head CT, or patients with a normal head CT if they had two or more of the inclusion criteria: age older than 40, motor posturing, SBP less than 90 mm Hg. While these characteristics frequently describe the majority of patients who receive ICP monitoring at our institution, the most recent BTF guidelines removed these criteria as the relevant studies did not meet evidence standards. The only recommendation for monitoring is currently that ICP monitoring may reduce in-hospital and 2-week mortality.

The gold standard ICP monitor is an external ventriculostomy (EVD), and the BTF guidelines emphasize that these are favored because they allow for monitoring and treatment of ICP via CSF drainage, and they can be recalibrated, unlike other available monitors. The recommendation is to treat ICP of more than 22 mm Hg because ICP above this threshold is associated with increased mortality.

Prior to any procedures, it is imperative that a full set of labs be checked to ensure platelets and coagulation markers are within normal limits. If possible, a medication history should be obtained specifically asking about antiplatelet and anticoagulation agents. Appropriate reversal agents should be administered as needed. In addition, any patient with concern for elevated ICP should have a chem 7, full electrolyte panel, and serum osmolality drawn on admission to aid treatment planning.

The location of EVD placement requires additional consideration in patients with traumatic injuries or fractures. In general, we prefer right-sided ventriculostomies to minimize disruption of eloquent cortex. In cases with significant left-side hemorrhage or injury, we consider an ipsilateral EVD to avoid further injury should a peri-catheter hemorrhage arise.

Patients undergoing medical management of elevated ICPs should have central venous access and arterial lines placed to allow administration of medication and maintenance of blood pressure goals in accordance with BTF guidelines (SBP >100 patients 50–69, >110 for patients 15–49 and >70). Consideration may be given to placement of a Swan-Ganz catheter in patients who require barbiturate coma for ICP management.

Following placement of the EVD, the patient's ICPs were noted to be 25–30 despite drainage of CSF. Additional medical interventions were begun. Short-term temporizing approaches include hyperventilation to decrease P_{CO_2} and sitting the patient upright. These interventions should be instituted while additional medications are being obtained and should not be used as the sole means of addressing persistently elevated ICP. The only recommendation in the 4th edition BTF guidelines regarding hyperventilation is Level IIb, that prolonged prophylactic hyperventilation is not recommended. Previous editions specifically recommended hyperventilation as a temporizing measure. While this recommendation was removed because it was based on literature that did not meet inclusion criteria for the 4th edition (case series only), it may still be a useful temporizing measure while medications are being obtained or operative intervention is being arranged.

The benefit of ICP monitoring via an EVD includes the ability to drain CSF for management of elevated ICP: the available guidelines are Level III recommendations that continuous drainage via an EVD zeroed at the midbrain may be more effective than intermittent drainage and that CSF drainage may be considered in patients with GCS of less than 6 in the first 24 h. This is a new topic in the 4th edition of the guidelines, and additional high-quality studies are needed to enable more thorough recommendations in future editions.

The most recent BTF guidelines state that while hyperosmolar therapy may decrease ICP, there is insufficient evidence to recommend a specific agent (i.e., mannitol, hypertonic saline) for this therapy. Earlier editions of the guidelines stated that mannitol in doses of 0.25–1 g/kg was effective in reducing ICP and recommended using mannitol either in patients with evidence of elevated ICP on intracranial monitor or in patients with clinical evidence of herniation syndromes or progressive neurological deficit.

Pharmaceutical methods of treating elevated ICP include intermittent boluses of narcotics (our institution frequently uses fentanyl), continuous drip of these medications, continuous drip of sedating agents (i.e., Precedex, propofol), or the use of barbiturates to induce burst suppression on EEG for intractable ICPs. Level IIb recommendations suggest barbiturate-induced burst suppression should not be used prophylactically but may be used for refractory ICP provided hemodynamic stability is maintained. Propofol is recommended for control of ICP, with the caveat that it does not improve mortality or 6-month outcomes. In patients being treated with high-dose propofol for ICP management, it is important to monitor creatinine, creatinine kinase, and clinical signs of renal function to ensure that propofol infusion syndrome (PRIS), which carries a high mortality rate in itself, does not occur.

The BTF guidelines do not recommend prophylactic hypothermia; however, hypothermia remains an option in the ICP management pathway for patients with refractory elevated ICP. Hypothermia may be achieved with cutaneous cooling pads or via a central venous catheter system. Central access may minimize shivering but does not obviate it. Our protocol is to begin by cooling patients to 35°C, using BuSpar and magnesium continuous infusions as prophylaxis against shivering. In patients who develop significant shivering, we attempt counter-warming with heated air blankets (i.e., Bair Hugger). If this fails, and if shivering affects ICP management, a paralytic infusion such as rocuronium is strongly considered. Of note, patients with severe shivering at 35°C may be cooled to 33°C, which minimizes the physiologic shivering response. Patients who are undergoing therapeutic hypothermia treatment, who do not have clinical shivering, but continue to have elevated ICPs, may be having micro-shivering and may also benefit from a paralytic. During hypothermia, the physiologic response is to force potassium intracellularly, leading to hypokalemia on daily lab checks. However, as rewarming will reverse this process, we recommend judicious repletion of potassium in these patients, with a goal around 2.5–3.0 provided there are no EKG changes, to avoid severe hyperkalemia upon rewarming.

Surgical Procedure

The details of operative intervention for intractable increased ICP are described in a separate chapter.

Operative intervention should be considered in patients where medical treatment options for elevated ICP (as detailed in the prior section) have been exhausted and in patients where imaging demonstrates clear mass effect/midline shift. It is imperative that the treating neurosurgeon and critical care teams be familiar with all medical treatment options and that consideration is given to how far along the pathway (hypothermia, barbiturate coma, etc.) they want to proceed before operative intervention is offered.

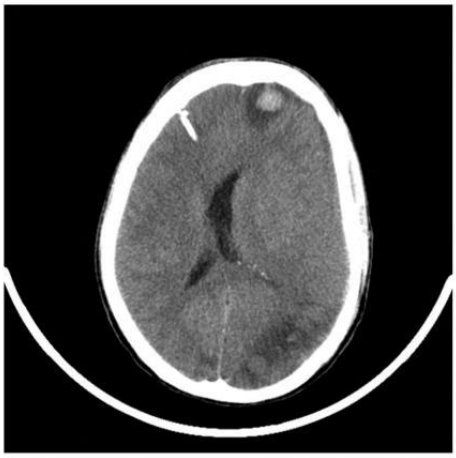

Figure 1.2 (A&B) Axial CT brain showing large left occipital/suboccipital epidural hematoma with mass effect.

It is likewise paramount that frank conversations are had with the patient's family and decision makers. The patient's age, general medical condition, extent of intracranial injury, and presence of other injuries are all important factors to consider when discussing prognosis, goals of care, and surgical intervention.

In our patient, we discussed at length with his family that despite aggressive medical management, his ICP remained high, and, given the evolution of his intracranial injury on repeat head CT (Figure 1.2), we recommended a decompressive hemicraniectomy as our next treatment option. In our conversations with any patient's family, we stress that operative intervention is designed to reduce the risk of mortality but may not effect overall functional prognosis or neurological recovery. The BTF guidelines specify that bifrontal craniectomies do not improve outcomes but successfully reduce ICP and lead to decreased ICU stay; frontotemporoparietal craniectomies deompressive hemicraniectomy (DHC) more than 15 cm diameter reduce mortality and may improve neurological outcomes.

Oral Boards Review: Management Pearls

- Traumatic injury causing clear mass effect, midline shift, or depressed skull fracture requiring repair should be managed with initial surgical intervention. Intraoperative placement of an ICP monitor should be considered.
- Escalating medical management using CSF drainage, temporizing measures, hyperosmolar therapy, sedation, and barbiturate coma should be considered.
- PRIS is a potentially fatal complication. Long-term high-dose propofol should be avoided; renal function should be monitored during treatment course.
- Early and frequent family discussions should occur. The mortality rate and neurological prognosis should be frankly described. Patient condition, age, and other injuries should be considered.

- Surgical intervention requires clear communication between the surgeon, operating room team, and anesthesia team. Adequate equipment and supplies should be confirmed; complications or intraoperative emergencies should be anticipated and clearly communicated to entire team along with a contingency plan.

Aftercare

Immediately postoperatively, patients require close monitoring of ICP to ensure it does not remain elevated. We consider weaning hyperosmolar therapy in this period provided there are no ongoing issues with ICP.

Nursing staff, critical care team, and house staff should be educated regarding the status of the hemicraniectomy flap at the conclusion of the case, to have a baseline for future evaluations. We recommend having all team members assess the patient after return from the operating room.

Slow reversal of sedating agents should be planned, with close monitoring of hemodynamic status, cEEG, and ICP. There should be contingency plans for re-escalating medical management if elevated ICPs recur. It is imperative these plans be consistently communicated between the surgeon, critical care team, house staff, and any night-float/weekend coverage/on-call teams.

Pivot Points

- The initial head CT should be assessed for surgical lesion. If this is present, initial management should be operative. If not, consider ICP monitor, and medical management for ICP of more than 22 mm Hg.
- Early family discussions should focus on course of care and interest in operative management. If family does not want to pursue surgery, exhaustive medical therapy, included barbiturate coma and hypothermia, should be considered. If family wants surgery, consider a contingency plan for what point in escalating medical management will prompt a trip to the operating room.
- Although the BTF guidelines have changed, the 3rd edition criteria for ICP monitoring may be considered in determining which patients require ICP monitoring and which may be observed via clinical exam. If the patient has GCS of less than 8 and an abnormal head CT, or a normal head CT but meets two or more of the criteria (age older than 40, motor posturing, SBP less than 90 mm Hg), it is reasonable to consider a monitor. If the patient has GCS of greater than 8, monitoring exam with minimal sedation remains an option.

Complications and Management

Medical management options are not without complications. Hyperosmolar therapy with mannitol can lead to hypotension, while hypertonic saline may lead to cardiac

arrhythmias and renal dysfunction. Vasopressors required to maintain goal SBP or mean arterial pressure (MAP) while patients are receiving hyperosmolar therapy, sedation, or barbiturate-induced burst suppression may cause peripheral vascular constriction with injury to extremities; if peripheral IVs are used, infiltration can cause compartment syndrome, tissue necrosis, and limb loss.

Patients with high-dose sedation needs may demonstrate hypotension and bradycardia (particularly with Precedex). High-dose propofol may lead to PRIS with potentially fatal results. Avoiding doses of more than 4 mg/kg/h for more than 24 h is recommended. Daily checks of triglycerides, creatinine/BUN, and creatinine kinase may catch PRIS early.

In patients requiring barbiturate-induced burst suppression, complications may arise when discussing end-of-life care, particularly in patients in whom progression to brain death is suspected or whose families wish to pursue organ donation options. The half-life of phenobarbital or pentobarbital, the most commonly used long-acting barbiturates in our institution, is 50–120 h. Drug level testing is available but is often sent to outside facilities, and it may take days to obtain a result. While barbiturates may be necessary for managing intractable ICPs, in families who are considering organ donation, a discussion about the challenges of these medications in assessing brain death may be beneficial.

Central venous access is recommended for patients requiring medical management of elevated ICPs, but these lines may lead to infection, fistula formation, accidental cannulization of an artery, hemo/pneumothorax, nerve injuries, or air emboli during line removal.

Hypothermic therapy may be achieved through central cooling catheters or cutaneous cooling pads. Central catheters carry the risks of line placement. Cutaneous cooling pads may limit the patient's ability to undergo scans (i.e., MRIs, lower extremity ultrasound for deep venous thrombosis screening), and can cause skin breakdown and frostbite. In extreme cases tissue damage requires management with hyperbaric oxygen and management in specialized burn centers. Frequent skin checks, particularly in patients with consistently low water-bath temperatures, are necessary to avoid serious injury.

The placement of an ICP monitor or EVD may lead to superficial skin infection, meningitis, or ventriculitis; despite best efforts, already injured brain is friable, and there is a risk of worsening, possibly life-ending intracranial or intraventricular hemorrhage following the procedure.

Infections in general are best managed through avoidance: proper sterile technique, limiting staff in the room, hair clipping when applicable, and clean dressings. There remains controversy surrounding the benefit of administering prophylactic antibiotics during bedside ventriculostomy procedures. While continued antibiotic coverage is not recommended, a single peri-procedure dose of antibiotics to cover skin flora may reduce the rate of ventriculostomy-associated infections.

Postoperatively, wound dehiscence is a potential complication, often exacerbated by patients who have limited ability to change position, where the hemicraniectomy site (other than bifrontal) may remain dependent, particularly the posterior-inferior aspect. Frequent repositioning, including using blankets or foam pillows to off-load the posterior scalp and maintain head rotation in alternating directions may help alleviate the problem. Daily wound checks are essential, and good communication with family