A Joint Trauma System Clinical Practice Guideline: Traumatic Brain Injury Management and Basic Neurosurgery in the Deployed Environment

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ABSTRACT Management of the patient with moderate to severe brain injury in any environment can be time consuming and resource intensive. These challenges are magnified while forward deployed in austere or hostile environments. This Joint Trauma System Clinical Practice Guideline provides recommendations for the treatment and medical management of casualties with moderate to severe head injuries in an environment where personnel, resources, and follow-on care are limited. These guidelines have been developed by acknowledging commonly recognized recommendations for neurosurgical and neuro-critical care patients and augmenting those evaluations and interventions based on the experience of neurosurgeons, trauma surgeons, and intensivists who have delivered care during recent coalition conflicts.

INTRODUCTION

The goal of this Joint Trauma System (JTS) Clinical Practice Guideline (CPG) is to provide guidelines and recommendations for the treatment and management of casualties with moderate to severe head injuries in an environment where personnel, resources, and follow-on care may be limited. Figure 1 gives a summary of these recommendations as well as process improvement metrics the JTS tracks in the care of these patients. Often virtual telehealth support is needed in the deployed environment. Figure 2 describes how to obtain routine, urgent, or emergent telehealth support in managing head injuries or other conditions in resource-limited environments. These traumatic brain injury guidelines are not intended to supplant physician judgment. Rather, these guidelines are intended to provide a basic framework for those less experienced with the delivery of care in this setting to the brain-injured patient, as well as to educate and provide insight to others on the delivery of care in a restrictive environment. Supplementary Box 1 lists the other CPGs referenced within this guideline as well as the full "Traumatic Brain Injury Management and Basic Neurosurgery in the Deployed Environment" CPG.

BACKGROUND

Traumatic brain injury (TBI) occurs in about one-third of all trauma-related deaths in the United States and remains one of the most common causes of death on the modern battlefield.[1,2] The Committee on Surgical Combat Casualty Care (CoSCCC) published a Neurosurgical Capabilities Position Statement in February 2023, given the importance of this issue.[3] Specific to the combat environment:

- Positive outcomes are achieved through point of injury care to prevent secondary brain injury (avoid hypoxia, avoid hypotension), rapid evacuation from the battlefield, early medical management, timely neurosurgical intervention, meticulous critical care, and dedicated rehabilitation.[4–11]
- Optimal outcomes for severe TBI (Glasgow Coma Score [GCS] ≤8) in theatre require a neurosurgical capability defined as a neurosurgeon, advanced imaging, required surgical sets, required monitoring, and critical care.[3,4]
- For conflicts in Afghanistan and Iraq, Department of Defense Trauma Registry (DoDTR) data demonstrate:[12,13]
  - 14% of casualties sustained a traumatic brain injury.[12]
  - TBI was the mechanism of death for 30% of prehospital deaths from 2001 to 2011 and 45% of hospital deaths from 2001 to 2009.[14]

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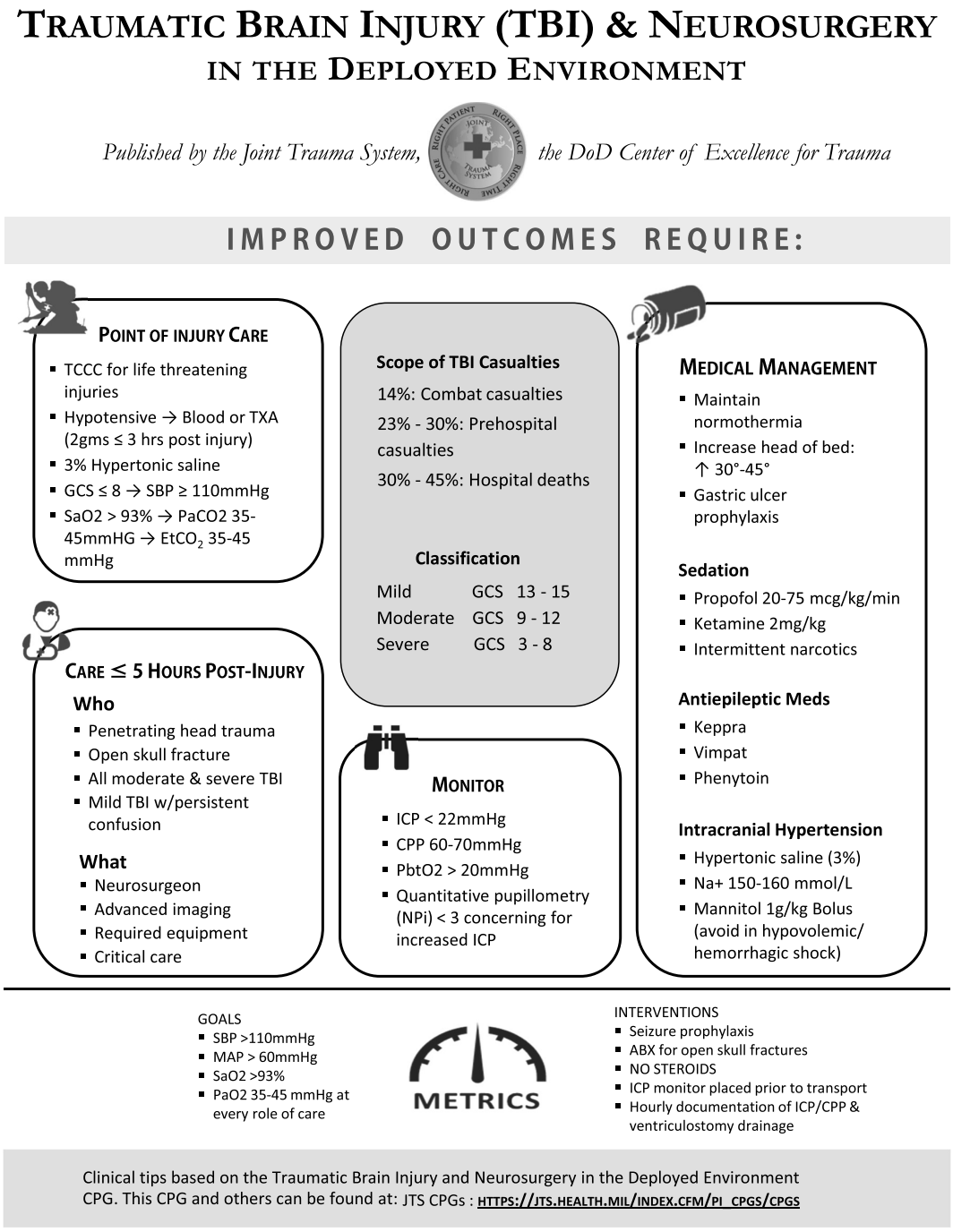

FIGURE 1. Summary of recommendations.

- From 2014 to 2021, Armed Forces Medical Examiner System (AFMES) data demonstrate TBI accounted for 23% of prehospital deaths and 30% of hospital deaths (Unpublished JTS-AFMES data).
- Over 5,600 neurosurgical procedures were performed in-theater between 2002 and 2016.[14]
- Casualties with a TBI and an indication for neurosurgical intervention were more likely to survive if they received surgery within 5 hours of injury.[11]
- Neurosurgical interventions performed on the battlefield after penetrating injuries result in improved survival.[7]

- Severe TBI also occurs during routine and crisis contingency operations, both ground and maritime combat, with an associated mortality of 69.7%.
- The incidence of TBI after non-combat maritime mass casualty events such as collisions is 5.8%; during modern naval warfare when warships are attacked by missile strikes

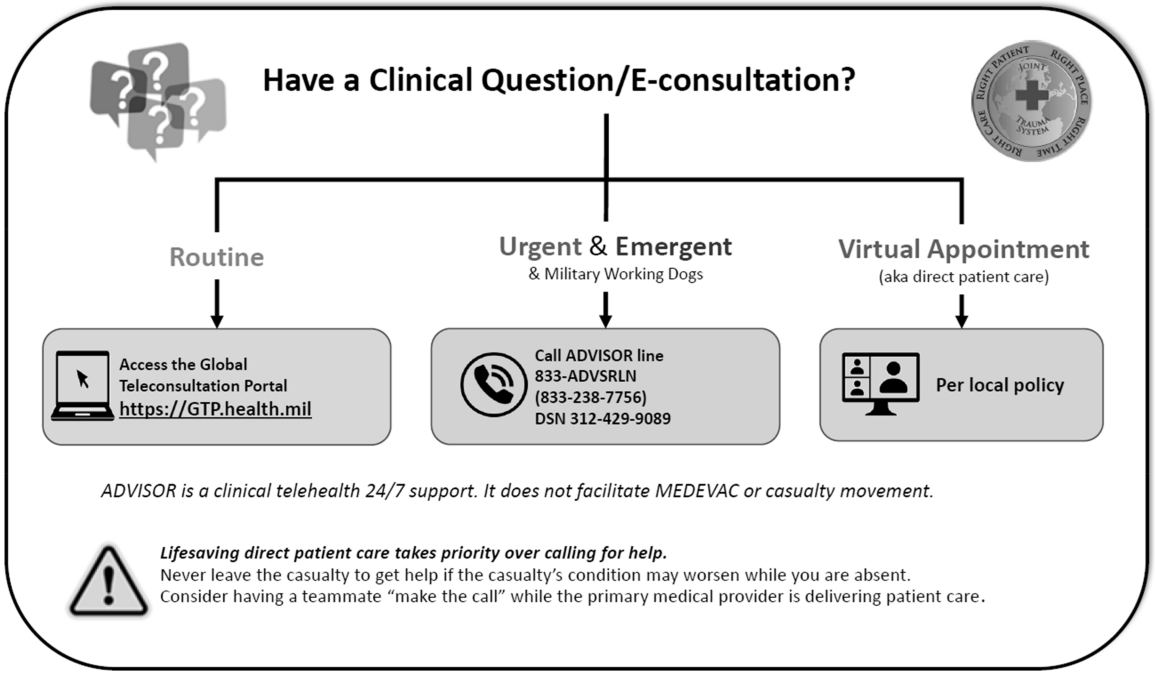

FIGURE 2. Telehealth support.

TABLE I. Glasgow Coma Score

Glasgow coma score	Eye opening	Best verbal effort	Best motor effort
1	None	None	Flaccid
2	To pain	Nonspecific sounds	Decerebrates to pain
3	To verbal stimuli	Inappropriate words	Decorticates to pain
4	Sponta-neous	Confused	Withdraws to pain
5	–	Oriented	Localizes to pain
6	–	–	Follows commands

or other explosive devices, the incidence of severe TBI is 17.2%.[15]

- Some patients with severe closed and penetrating brain injury had favorable outcomes when treated in military medical treatment facilities (MTFs) and received timely and aggressive neurosurgical and neuro-critical care interventions.[2,5–7,11]

CLASSIFICATION

The classification of brain injury informs prognosis and care eligibility in the combat environment. Brain injury severity is classified according to their Glasgow Coma Score (GCS) (**Table I**).

- Mild: GCS 13 to 15
- Moderate: GCS 9 to 12
- Severe: GCS 3 to 8

Neurosurgical care capabilities are available at designated Role 3 facilities, Role 4 facilities, and inpre-identified partner nation facilities.

ROLE 3 TRANSFER FOR NEUROSURGICAL EVALUATION & CARE

Neurosurgical care in a combat theater is a limited resource and often requires air transport to get patients to the closest neurosurgeon or even Computed Tomography (CT) for diagnosis and treatment. Both over- and under-utilization should be avoided.

Coalition Casualties

- Coalition casualties may require transfer for formal evaluation with a CT scan and/or a neurosurgeon when they:
  - continue to have a GCS <14 (mild TBI needs further evaluation in coalition casualties if the GCS does not return to GCS of 15).
  - are confused or have continued cognitive deficits.
- The MACE2 is validated for determining the presence of an mTBI and should be used as an initial screening tool for to evaluate mTBI. It should not be used to determine worsening intracranial injury.[16–18]
- All coalition casualties should be referred for neurosurgical evaluation if they have:
  - Penetrating brain injury
  - Open skull fracture
  - Moderate or severe brain injury
  - Head trauma AND unexplained neurologic deficits

Host Nation (Hn) Casualties

- Management of host nation casualties should be in accordance with medical rules of eligibility (MEDROE) established for the area of responsibility. TBI management and neurosurgical care of HN casualties are MEDROE dependent. Providers should care to the best of their capabilities for HN TBI patients and involve the theater Trauma Medical Director (TMD) and neurosurgery (NS) early in the management.
- When MEDROE permits, moderate brain injury in HN casualties should be referred to Role 3 facilities with neurosurgical capability for definitive care.
- All patients should ethically receive equal care; however, the realities of combat are that HN casualties with severe brain injury have a poor prognosis when follow-on care is not available after discharge from the military MTF. The decision to transfer HN casualties with severe brain injury to Role 3 is based on mission, tactical situation, and resource availability and is ideally preceded by direct communication and discussion with the TMD and neurosurgeon.
- Depending on the severity of TBI, considerations for transfer of HN casualties to HN facilities after Role 3 MTF care can be complicated, multifactorial, and dependent on current MEDROEs. HN patients may not receive optimal care after leaving the military MTF, which adds to the complexity of decision-making for the care of these patients. For patients with severe TBI and poor prognosis, palliative care at the in-theatre MTF may be most appropriate. These decisions should be made in the context of TBI severity and the available continuum of care for the patient in their nation of origin. Discussions with the theater neurosurgeon, TMD, and command elements can aid in this difficult decision.

EARLY EVALUATION AND TREATMENT

The initial management of the patient with brain trauma begins with addressing life-threatening injuries and resuscitation in accordance with Tactical Combat Casualty Care (TCCC) guidelines in the field for corpsmen and combat medics or Advanced Trauma Life Support (ATLS) providers.[19] Supplementary Box 2 gives a summary of key interventions in initial severe TBI treatment.

Simple Physical Interventions to Implement Early

- Head of bed elevated to 30-45° or reverse Trendelenburg (if in spinal precautions)
- Keep head straight to avoid kinking of the internal jugular veins (to promote venous drainage)
- Avoid tight cervical collars and tight circumferential endotracheal tube/tracheostomy tube ties

- Imaging: Patients with a suspected traumatic brain injury with altered mental status (GCS 12 or less) should have a non-contrast head CT as soon as possible. For penetrating head injuries, in addition to the non-contrast head CT study, a CT angiogram of the brain should also be obtained to evaluate for vascular injuries (e.g., pseudoaneurysms).
- "Blood products" are the "preferred resuscitative fluid for hypotension in all trauma patients." Avoid Albumin and hydroxyethyl starches; albumin is associated with worse outcomes when used in TBI patients.[20,21]
- Tranexamic acid: All patients with evidence of moderate or severe TBI should be administered 2 gm of TXA within 3 hours of injury; 2 gm of TXA in TBI patients improves survival.[22]
- "If severe TBI is suspected, antiepileptics (Keppra, 1500 mg loading dose) should be administered during the initial evaluation and within 30 minutes of arrival."
- "For casualties with abnormal GCS who do not require resuscitation" for hypotension or major blood loss, use normal saline or 3% hypertonic saline for volume resuscitation. Both have shown equivalent outcomes in severe TBI. "Avoid hypotonic fluids (e.g., any IVF with Dextrose % in water [D5W])."
- "For casualties with GCS $\leq$ 8," manage hypotension by maintaining systolic blood pressure greater than 110 mmHg.[4] A "systolic blood pressure of less than 90 mmHg is the single risk factor most highly associated with mortality in brain trauma."[23,24]
- "End tidal CO_2 ($EtCO_2$)" should be monitored during prehospital care and continued after handoff to a surgical team. Normoventilation with a goal partial pressure of carbon dioxide "($PaCO_2$) of 35-45 mmHg should be maintained or $EtCO_2$ of 35-45 mmHg. DO NOT hyperventilate."
- "Prophylactic hyperventilation is not recommended" as it decreases cerebral blood flow. It may be used as a temporizing measure to reduce intracranial pressure in the setting of suspected herniation until other therapies are employed to decrease intracranial pressure as the patient is on the way to the operating room.[25] Hyperventilation can be harmful.[4]
- "For penetrating brain injuries and open skull fractures, routine prophylactic antibiotics" are indicated.[26] Antibiotic recommendations for the first level of surgical care include either cefazolin 2 gm IV every 6 to 8 hours or clindamycin 600 mg IV every 8 hours. If a penetrating head injury appears grossly contaminated with organic debris, consider addition of metronidazole 500 mg IV every 8 to 12 hours.[26]
- "For isolated closed head injuries," routine prophylactic antibiotics are not indicated.
- "Hypoglycemia and hyperglycemia must be avoided. Monitor glucose" every 6 hours. The goal is to maintain glucose <180 mg/dl and avoid hypoglycemia.[27] "D5W IVF" will "worsen cerebral edema. Do NOT use intravenously" to maintain euglycemia.
- "Steroids should be avoided in brain-injured patients" as they have not shown outcome benefit and increase mortality in patients with severe brain injury.[25,28]
- "A common strategy for management of hypoxemia" has been a goal of arterial oxygen saturation (SaO2) >90%

and the partial pressure of oxygen in the arterial blood (PaO2) >60 mmHg.[24] However, in order to establish a safety buffer in the deployed setting often characterized by frequent patient handoffs and occasional equipment challenges, a "goal SaO2 of 93% and PaO2 >80 mmHg" is recommended. Particular attention to avoidance of hypoxemia during air transport is essential as human studies and animal models indicate hypoxia during aeromedical evacuation is common.[29,30]

- "Document serial neurological exam findings every hour," including:
  - Glasgow Coma Score broken down by eyes, voice, motor scores. (See **Table I**.)
  - Presence of gross focal neurologic signs and/or deficit.
  - Pupil size and reactivity.
  - When available, quantitative pupillometry should be assessed and documented to ensure accuracy and consistency of recordings.[31–33] Quantitative pupillometry and the neurologic pupillary index (NPi) allows objective and consistent assessment of pupillary reactivity to track trends and determine if a patient's responsiveness is worsening. ICU nurses should be documenting these findings and they should be trended.
  - NPi <3.0 is concerning for an abnormal or sluggish pupil and therefore increased intracranial pressure. NPi should be documented, and significant changes indicate the need to assess or empirically treat for increased intracranial pressure. If a neurosurgeon is not managing the patient; telehealth support to review NPi should be considered (Fig. 2). For additional information on pupillometry, see appendix C of the full CPG (Supplementary Box 1).

MEDICAL MANAGEMENT

Sedation

There is a delicate balance when sedating patients with TBI. When transferring casualties to a neurosurgical capability for initial assessment, avoid long-lasting sedation or paralysis as this impedes the ability to evaluate the patient. However, medication selection should not override the need to safely transport the casualty.

- Propofol can be used for sedation, but caution must be used to avoid hypotension.[25]
- Ketamine is also useful for sedation (and can also provide some analgesia) as it avoids the significant hypotension associated with propofol and there is evidence it lowers intracranial pressure (ICP).[34–40]
- When narcotics are utilized for pain management, intermittent narcotic doses are preferred over continuous infusion.
- Routine paralysis of TBI patients should be avoided. If paralytics are needed, vecuronium is preferred because it is readily available in the austere environment and does not require refrigeration. Bolus dosing is preferred over continuous infusion. The recommended initial dose is 0.08 to 0.1 mg/kg given as an intravenous bolus injection. Paralytics should only be used if the patient is appropriately sedated. In general, paralytics should only be used for high-risk transport.

Intracranial Hypertension

Despite controversy on the use of invasive monitoring to measure ICP, treatment of known or suspected intracranial hypertension remains a cornerstone of therapy in patients with severe brain injury.[41]

Intracranial hypertension should be suspected based on certain clinical criteria if no CT scan or intracranial monitor is available. These criteria include:

- GCS Motor Score <4
- Pupillary asymmetry
- Interval development of pupillary asymmetry ≥2 mm
- Abnormal pupil reactivity
- Decrease of motor score by ≥1
- New motor deficit
- Hypertension with Bradycardia
- If an automated pupillometer is present, an NPi <3 on one or both eyes is concerning for raised intracranial pressure.

If treatment for intracranial hypertension is indicated prior to arrival to a neurosurgical capability, initiate hyperosmotic therapy with one of the following:

1. **Hypertonic Saline**[41,42]
   - 250 mL bolus of 3% saline administered over 10 to 15 minutes or a 30cc bolus of 23.4% saline.
   - In a location with no neurosurgical capability for definitive treatment, infuse 3% saline at 50 to 100 mL/h for resuscitation with goal serum Na level of 150 to 160 mmol/L. If in the rare circumstance, chronic hyponatremia is suspected, elevation of plasma sodium by 3 to 5 mmol/L over 2 to 4 hours is recommended.
   - Place central venous access to administer hypertonic saline and vasoactive medications, particularly if it is anticipated to be needed long term. Subclavian veins are preferred, followed by femoral, and lastly internal jugular.
   - A Hypertonic Saline protocol can be found in Appendix B of the full CPG (Supplementary Box 1).
2. **Mannitol**

Avoid Mannitol during the initial resuscitation period when ongoing bleeding has not been ruled out and in hypotensive casualties (or any casualty with the risk of bleeding).

Consider using Mannitol only if there is no availability of hypertonic saline and there is a significant concern for imminent herniation as evidenced by signs of intracranial hypertension described above.

- Mannitol 1 g/kg bolus IV.[25]
- Hypotension after mannitol administration must be predicted and avoided. Urine output should be replaced with isotonic fluids.
- When treating patients with osmotic agents, monitor serum sodium at least every 6 hours.

Antiepileptic Medications and Seizures

Seizures are common after severe brain trauma. "Administer seizure prophylaxis" to avoid the hemodynamic changes and increased cerebral metabolic activity caused by seizures. Seizure medications help prevent early post-traumatic seizures, but do not prevent all seizures. Up to 25% of patients with severe TBI will have seizures even with prophylactic treatment. Fifty percent of seizures may be non-convulsive in nature. Patients with subdural hematoma, neurosurgical procedure, or penetrating brain injury are at the highest risk of seizures. Post-traumatic seizures have been shown to increase morbidity and mortality after trauma.[43–46] For additional information regarding seizure management, refer to Appendix A of the full CPG (Supplementary Box 1).

- If severe TBI is suspected, seizure prophylaxis should be administered during the initial evaluation and within 30 minutes of arrival.
    - Preferred agent: Levetiracetam (Keppra) 1,500 mg IV loading dose, followed by 1,000 mg IV BID
    - Second-line agent: Lacosamide (Vimpat) 400 mg IV loading dose, followed by 200 mg IV q12hours.
    - Continue seizure prophylaxis for 7 days after a moderate or severe TBI.[25,47–51]
    - Seizure medications should be continued past post-injury day seven if the patient had evidence of seizure activity.
    - Rapid assessment and treatment of seizures is important to prevent secondary neurologic insult. Use a rapid response EEG device (if available) to diagnose seizures accurately and quickly.[52–56]

Active seizures

Lorazepam 1 to 2 mg IV or Midazolam 5 to 10 mg IV. Lorazepam is preferred. If no IV access, Midazolam IM is as effective as Lorazepam IV.

Other Precautions

- Maintain normothermia. Avoid and treat hyperthermia.
- Elevate head of bed to 30-45° or use reverse Trendelenburg position for suspected concomitant spine/spinal cord injuries.
- Gastric ulcer prevention with an IV PPI should be started within 12 hours of admission.
- Consider enteral nutrition according to JTS Clinical Practice Guidelines (Supplementary Box 1) available at: Nutritional Support Using Enteral and Parenteral Methods.[57]

AEROMEDICAL EVACUATION CONSIDERATIONS

Coordinating care between sending and receiving physicians is of paramount importance during patient movement. Neurosurgeons should discuss all patients being transferred to Role 4 with the receiving neurosurgical team to ensure a common understanding of the patient and the risks and benefits of aeromedical evacuation. Casualties with severe TBI should be manifest with altitude restrictions and the cabin pressured to 5,000 ft. PaO2 and SaO2 should be closely monitored in flight given the risk of barometric changes in PaO2.[58]

Intracranial Pressure

ICP monitoring is recommended during aeromedical evacuation for patients who would meet the requirements stated below in the surgical management section.[59]

If appropriate neurosurgical capability and bed capacity are available, observation in theater may be warranted for patients with borderline ICP measurements. Stresses of flight including vibration, temperature, noise, movement, light, hypoxia, and altitude have been shown to increase ICP.[60,61]

Delayed evacuation may improve outcomes in patients with ongoing resuscitation needs and intracranial hemorrhage or decreased GCS. Since most intubated patients require heavy sedation and often paralysis during transport, neurologic exam cannot be followed and a neurologic deterioration may not be detected for many hours. Some patients have suffered herniation during long range evacuation. For example, this has occurred with patients who have significant burns requiring resuscitation who have intracranial hemorrhage or cerebral edema.

"Do not remove a functional ICP monitor in the immediate period prior to aeromedical evacuation."

This provides information to the Critical Care Air Transport Team (CCATT) team that can direct in flight treatment. Furthermore, it offers a level of safety in terms of stable ICP in patients who may otherwise require sedation or not have a reliable neurological exam.

Drains

"Do not remove drains in the immediate period prior to aeromedical evacuation" due to the risk of bleeding.

Pneumocephalus

The effect of increasing altitude on contained air within the body, including the cranium, will potentially result in expansion of pneumocephalus; this is particularly true for those who have not undergone a decompressive craniectomy prior to the flight.

All patients should be transported with head of bed elevation or reverse Trendelenberg at 30-45°. Typically, U.S. Air Force doctrine is to load all patient's feet first into the aircraft.[59] In a patient with TBI, the "aeromedical transport physician may consider loading headfirst, to maintain head elevation during flight."

Deep Vein Thrombosis Prophylaxis

All patients should be started on mechanical Deep Vein Thrombosis (DVT) prophylaxis at a minimum using sequential compression devices on uninjured extremities.

All trauma patients who are non-ambulatory require DVT prophylaxis, including brain-injured casualties. Chemical DVT prophylaxis in all moderate to severe head injured patients with normal coagulation profile should be started once there is a documented stable head CT, ideally no later than 24 hours after injury.

Caution in starting DVT prophylaxis and discussion with neurosurgeon is recommended for the following conditions:

- Polytrauma with or at risk for coagulopathy.
- Have intracranial monitor/drain in place.
- Have one or more of the following TBI features that are "high risk" for progression according to the Norwood-Berne criteria:
  - Subdural hematoma (SDH) $\geq$8 mm
  - Epidural hemorrhage $\geq$8 mm
  - Largest single contusion $\geq$2 cm
  - More than one contusion per lobe
  - Diffuse or scattered subarachnoid hemorrhage.
  - Diffuse or scattered intraventricular hemorrhage.

For these patients, chemical prophylaxis may be started 72 hours post-injury or as neurosurgeon recommends (reference)[62,63]

Enoxaparin 30 mg subcutaneous BID (preferred) or subcutaneous heparin, 5,000 U TID may be used as chemoprophylaxis.[25,64–66]

MULTIMODALITY MONITORING OF HEAD INJURIES

Non-operative management of intracranial hemorrhage requires neurosurgical consultation, repeat imaging until CT scan is stable, and serial exams.

Surgical intervention may be indicated in the management of patients with severe brain injury. This includes operative care such as evacuation of space-occupying hematomas via craniectomy or craniotomy as well as placement of multimodal intracranial monitors.

Intracranial Pressure Monitoring

Management of "severe TBI patients" using information from ICP monitoring is recommended. Although long-term outcomes have not been shown to be improved with ICP monitoring, there is evidence that in-hospital and 2-week post-injury mortality is improved.[4] Additionally, the military trauma system may require multiple patient movements and handoffs that decrease the ability to follow neurologic exams. Therefore, ICP monitoring may detect a deterioration that would normally be detected on serial neurologic exam in a stable ICU environment.

ICP monitoring should be considered in all salvageable patients with:

- Severe TBI and abnormal CT showing one or more of the following:
  - Hematoma
  - Contusion
  - Edema
  - Herniation
  - Compressed basal cisterns.[25]
- Severe TBI and a normal CT if 2 or more of the following are noted:
  - Age >40
  - Unilateral or bilateral posturing
  - Systolic blood pressure <90 mm Hg.[25]

Additionally, a "low threshold for ICP monitoring" should be maintained in severe TBI patients with "any abnormal head CT and inability to follow serial neurologic exam" such as during other surgical interventions required early after injury, long-range evacuation of intubated patients, etc.

Options for ICP monitoring[25]:

- External ventricular drain (ventriculostomy tube)
- Parenchymal ICP monitors. Codman ICP monitors are the only intraparenchymal device with aeromedical certification approved for U.S. Air Force aircraft.

If using antibiotic impregnated ventriculostomy, then no IV prophylactic antibiotics are required. Otherwise, Ancef 1 gm IV TID may be prescribed while ventriculostomy is in place (neurosurgeon's discretion).

"The goal ICP is <22 mmHg."[25]

Cerebral Perfusion Pressure

Cerebral perfusion pressure (CPP) is defined as: CPP = mean arterial pressure (MAP)-ICP.[4] The goal CPP is between 60 and 70 mmHg when the autoregulator status of the patient is uncertain.

Brain Tissue Oxygen Monitoring

- Aeromedical evacuation may decrease continuous brain tissue oxygen (PbtO2).[33,67,68] There is evidence that the combined management of PbtO2 and ICP may improve outcomes of neurologic function in patients with severe TBI.
- Consider placement of a multi-modality intra-parenchymal catheter for monitoring of both PbtO2 and ICP
- PbtO2 should be maintained greater than 20 mmHg.
- For additional information on strategies for managing PbtO2 and ICP, review Appendix A of the full CPG (Supplementary Box 1)

Note: This monitoring capability may not be readily available; parameters have been outlined here in case these monitoring strategies are applicable in the future.

INDICATIONS FOR NEUROSURGICAL INTERVENTION

Epidural Hematoma

All epidural hematomas >30cc should be surgically evacuated regardless of the patient's GCS.[25]

EDH <30cc and with less than 15 mm thickness and less than 5 mm midline shift with a GCS >8 without a focal deficit may be managed non-operatively with appropriate monitoring in the ICU setting. These patients should be urgently transported to an MTF with neurosurgical capability for monitoring in case they decompensate.

Subdural Hematoma

Craniotomy for evacuation of an acute SDH with a thickness >10 mm or midline shift >5 mm regardless of the patient's GCS.

Craniotomy for evacuation of acute SDH with a thickness <10 mm and shift <5 mm is indicated when there is a decrease in GCS of 2 or more, worsening pupillary exam, and/or and ICP greater than 20mm Hg.[25]

Traumatic Parenchymal Lesion

Craniotomy for evacuation of a hematoma is indicated in a patient with GCS of 6 to 8 with frontal or temporal contusions greater than 20cc in volume with midline shift or at least 5mm and/or cisternal compression on CT.[25]

Craniotomy for evacuation of a hematoma is also indicated in patients with lesions greater than 50cc in volume in a salvageable patient.

Posterior Fossa Mass Lesion

Mass effect on non-contrast CT or with neurological dysfunction or deterioration due to the lesion should undergo operative intervention as soon as possible.[25]

Traumatic Aneurysms

A high index of suspicion is required for penetrating injuries of the skull base or across known major vascular territories. All penetrating brain injuries should undergo a CT Angiogram or Digital Subtraction Angiogram to rule out or diagnose a traumatic aneurysm as soon as possible.[10]

Debridement

Removal of devitalized brain tissue is an option in penetrating head injuries and in select cases of open skull fractures.[69]

Foreign Body Removal

The routine pursuit of individual foreign bodies (e.g., bullets, metallic fragments, bone) within the brain may cause additional tissue damage and is generally not advisable but should be left to the discretion of the neurosurgeon. Removal of fragments from the sensory, motor, or language cortex may reduce the risk of posttraumatic epilepsy.[69,70]

Dural Management

Primary dural closure or limited duroplasty should be done in extremely limited instances as cerebral edema can progress in both severe and penetrating traumatic brain injury. Commonly, duragen or other dural substitute should be used as an overlay in the vast majority of cases during a decompressive hemicraniectomy. Dura can be reconstructed with temporalis fascia or fascia lata if a dural substitute is not available.[69]

Decompression

Surgical decompression, or craniectomy, should be strongly considered following penetrating combat brain trauma.[7,70–72]

The kinetics of combat trauma can be very different from that seen in the civilian setting. The muzzle velocities of military rifles are much higher than civilian handguns which may lead to cavitation and surrounding devitalized tissue. Additionally, blasts can create four to five different classes of injury to the brain and other organ systems complicating management.[72]

1. Primary blast injury: blast overpressure from pressure waves.
2. Secondary blast injury: penetrating fragmentation injuries.
3. Tertiary blast injury: displacement of the casualty or blast debris that falls on the casualty.
4. Quaternary blast injury: injury from the thermal effect or release of toxins from the blast.

During transport, interventions for intracranial hypertension are limited to medical management. Craniectomy and en route monitoring devices may facilitate earlier CCATT transport of patients out of theater; however, "long-range evacuation is not a benign intervention" and may increase secondary brain injury. "In cases of elevated ICP or in the early postoperative period, patients may be better served by delayed evacuation if possible."

Skull Flap Management

Options for United States and Coalition Patients:

1. Those who have penetrating brain trauma: Do not save or send the calvarium as alloplastic reconstruction techniques are used for these casualties.
2. Those who have blunt trauma: Consider abdominal subcutaneous implantation of the calvarial flap for later reconstruction if it can be done in a sterile fashion.

Options for Host Nation Patients:

1. Clean and replace.
2. Clean and replace with hinge craniectomy. This involves partial fixation of the superior aspect of the bone flap, allowing it to "hinge" outward to accommodate swelling.[77]
3. Craniectomy with potentially limited chances for cranioplasty in the future, depending on local rules of eligibility.

4. In some locations, low temperature tissue freezing may be possible to allow replacement at a later time.

EXPLORATORY BURR HOLES (if no neurosurgeon or CT scan is available)
"Exploratory burr holes have limited practical utility." They should "only be performed by a neurosurgeon or after consultation with a neurosurgeon" if possible and at a location where CT scan is not available to better guide management. Refer to the JTS CPG entitled Emergency Life-Saving Cranial Procedures by Non-Neurosurgeons in Deployed Setting for additional guidance.
ICP MONITORING AND SURGICAL INTERVENTION (for Host Nation Patients)
Decisions to place ICP monitors or operate on host nation nationals should consider the available resources in the host nation for long-term care and rehabilitation.

PERFORMANCE IMPROVEMENT MONITORING

The JTS routinely tracks process improvement metrics in the Department of Defense Trauma Registry. The population of interest for this CPG includes:

- All patients with a diagnosis of traumatic brain injury and an initial GCS of 3 to 8.
- All patients who receive a cranial procedure (ICP monitor, craniectomy, craniotomy).

Intent (Expected Outcomes)

- All patients in population of interest avoid hypotension and hypoxia: SBP never <110 mmHg, MAP never <60 mmHg, SaO2 never <93%.
- All patients in population of interest have $PaCO_2$ monitored at every role of care; PaCO2 should not be >45 mmHg or <35 mmHg.
- All patients in population of interest have a head CT performed within 4 hours of injury and surgical intervention (if necessary) within 5 hours of injury.
- All patients with a ventriculostomy have hourly documentation of ICP/CPP and ventriculostomy output.
- All patients in population of interest who are unable to be monitored clinically (e.g., unable to hold sedation for Q1 hour neuro exam) have an ICP monitor or ventriculostomy placed prior to transport out of theater.

CONCLUSION

The management of patients with moderate to severe traumatic brain injury is resource intensive, time consuming, and challenging in the deployed or austere setting. This Joint Trauma System Clinical Practice Guideline provides recommendations for the treatment and medical management these types of brain injuries in environments where personnel, resources, and follow-on care are limited. Positive outcomes are achieved through point of injury care to prevent secondary brain injury by avoiding hypoxia and hypotension, rapid evacuation from the battlefield, early medical management, timely neurosurgical intervention, meticulous critical care, and dedicated rehabilitation. For patients with severe traumatic brain injury who do not require initial surgical intervention, Intercranial Pressure monitoring is recommended particularly during patient movement through the military trauma system. Management of host nation patients requires consideration of local capabilities for follow-on and supportive care.

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BD, RM, and CN drafted the manuscript. All authors reviewed and edited the manuscript. All authors read and approved the final manuscript.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Military Medicine* online.

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None declared.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

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