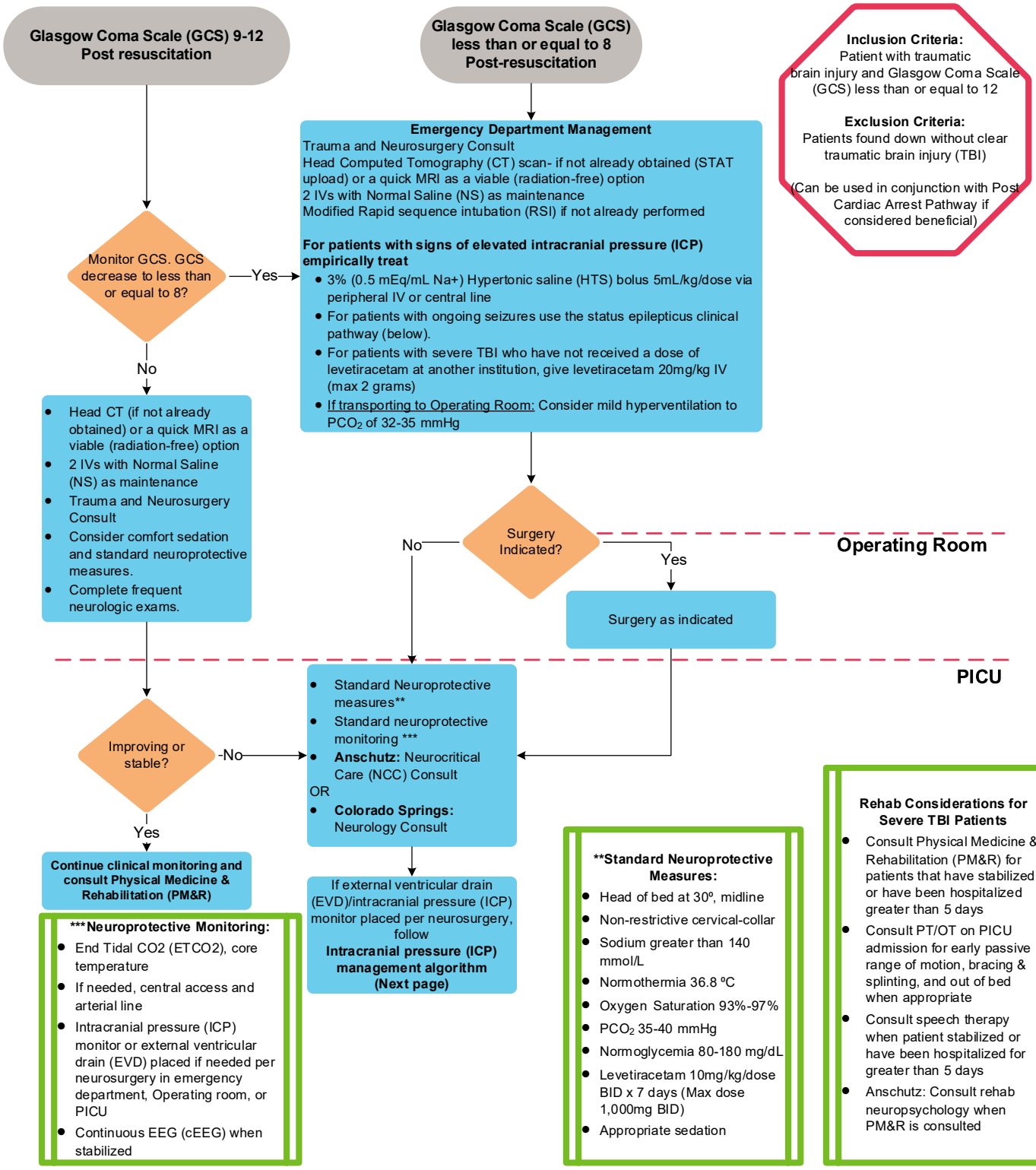
Traumatic Brain Injury (TBI): Moderate/Severe

ALGORITHM 1: Post-Resuscitation



*Post Cardiac Arrest Clinical Pathway
*Status Epilepticus Clinical Pathway

Algorithm 2. Moderate/Severe Traumatic Brain Injury (TBI) Intracranial Pressure (ICP) Management

Neuroprotective Monitoring:

- End Tidal CO2 (ETCO2), core temperature
- If needed, central access and arterial line
- Intracranial pressure (ICP) monitor or external ventricular drain (EVD) placed if needed per neurosurgery in emergency department, operating room, or PICU
- Continuous EEG (cEEG) when stabilized

Age (years)	MAP (mmHG)	ICP (mmHg)	CPP (mmHg)
0-2	50-70	Less than 15	40-55
2-5	60-80	Less than 15	45-65
6-8	65-85	Less than 20	45-65
9+	70-95	Less than 20	50-75

Mean Arterial Pressure (MAP), Cerebral Perfusion pressure (CPP)

Standard Neuroprotective Measures:

- Head of bed at 30º, midline
- Non-restrictive cervical-collar
- sodium greater than 140 mmol/L
- Normothermia 36.8 ºC
- O_2 Sat 93%-97%
- PCO_2 35-40 mmHg
- Normoglycemia 80-180 mg/dL
- Levetiracetam 10mg/kg BID x 7 days (Max dose 1,000mg BID)

Fluid Goals and Vasoactives

- Maintain cerebral perfusion pressure (CPP) and euvolemia
- If euvolemic, use ionotropic/ vasopressor support

Cerebral Spinal Fluid (CSF) Drainage:

- For patients with external ventricular drain (EVD) inform neurosurgery if ICP elevated greater than 20mmHg for more than 10 minutes
- If clamped, unclamp and place at 15 mmHg, do not raise if already lower then 15 mmHg
- Recheck ICP every 10 minutes
- Additional adjustments per neurosurgery

Comfort Sedation

- Richmond Agitation and Sedation Score (RASS) less than or equal to -1
- Comfort score 17-24
- With a goal of preserving a neurologic exam and safety for the patient

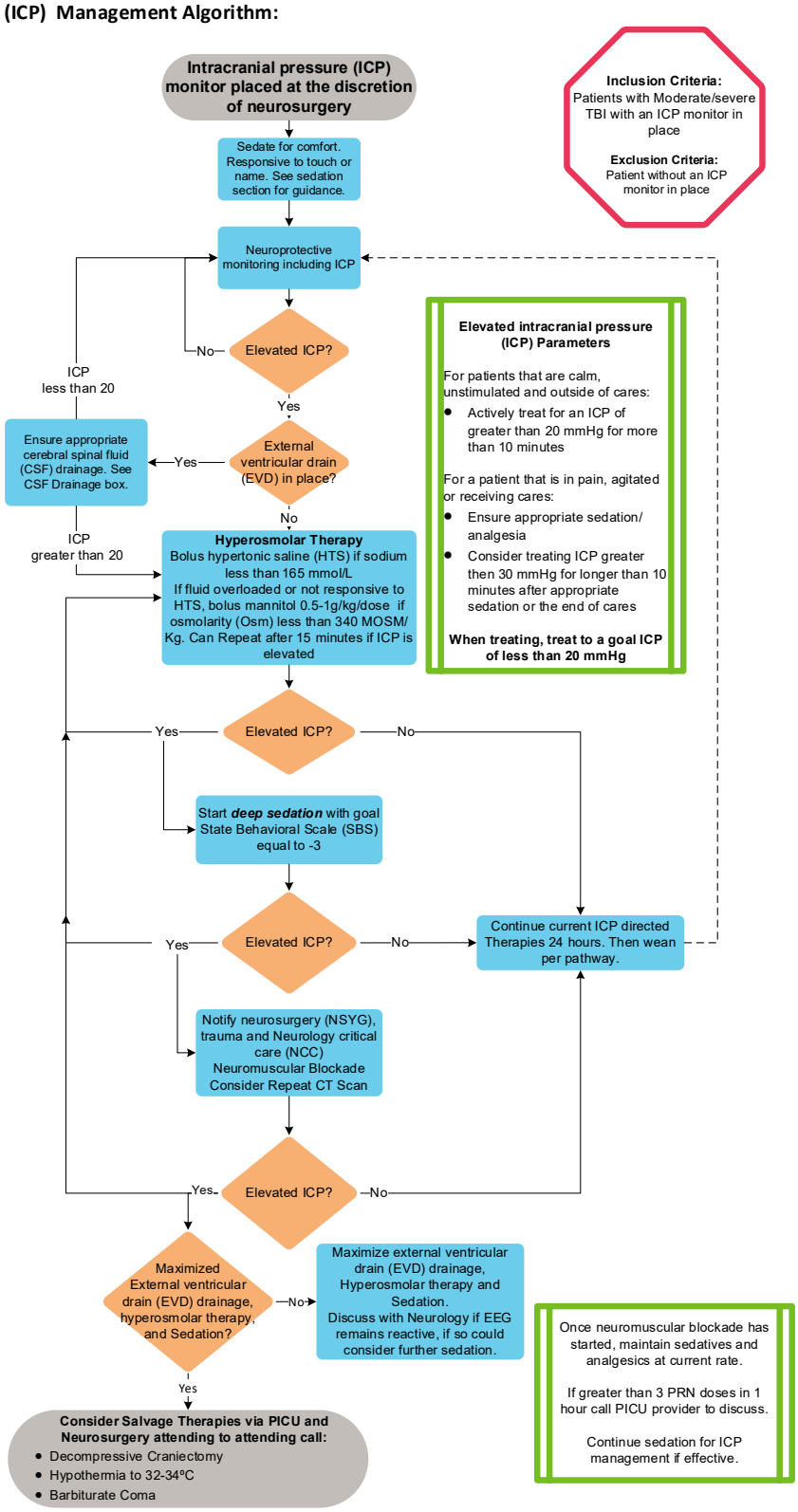
Deep Sedation

- Midazolam, fentanyl, or morphine
- Avoid hypotension
- Consider neuromuscular blockade if not ventilating or for refractory ICP
- Consider ketamine

Hyperosmolar Therapy

- Hypertonic Saline (HTS) is first line in patient with central venous line and not fluid overloaded
- 3% HTS may be administered via peripheral IV in emergent situations
- 12% (2mL/kg; Max=60mL) and 23.4% (1mL/kg; max=30mL) boluses via central venous line for fluid overloaded patients
- Mannitol 0.5-1g/kg/dose IV if HTS not available or refractory to HTS
- Monitor sodium and osmolarity (Osm) every 4 hours
- Sodium less than 165 mmol/L and osmolarity less than 340 MOSM/Kg

Moderate/Severe Traumatic Brain Injury (TBI) Intercranial Pressure (ICP) Management Algorithm:



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TARGET POPULATION

Inclusion Criteria

- All patients cared for at Children's Hospital Colorado with known or suspected brain injury secondary to trauma with a post-resuscitation Glasgow Coma Score (GCS) of less than 8 (Severe Traumatic Brain Injury) or GCS 9-12 (Moderate Traumatic Brain Injury) with concern for potential decompensation. This includes patients less than 2 years of age with concern for abusive head trauma.

Exclusion Criteria

- Patient found down without clear trauma

BACKGROUND | DEFINITIONS

This protocol is based on "The Guidelines for the Acute Medical Management of Severe Traumatic Brain Injury in Infants, Children, and Adolescents" and on the existing literature and is intended to provide standardization in the care of traumatic brain injury (TBI) patients at Children's Hospital Colorado.

Scope: Children's Hospital Colorado – Anschutz Medical Campus (CHCO-Anschutz)

Severe Traumatic Brain Injury: Glasgow Coma Score (GCS) of 3 – 8

Moderate TBI: GCS of 9-12

Mild TBI: GCS of 13-15

INITIAL EVALUATION & CLINICAL MANAGEMENT

Emergency Department Management:

- Obtaining the best neurologic exam safely is critical for neurosurgical decision-making and appropriate patient management. In all patients, Glasgow Coma Scale (GCS) is assessed. When possible, consider avoiding further sedatives and paralytics until neurosurgery resident or fellow examines patient. Call neurosurgery early when sedation or intubation may be necessary.
- When sedation or analgesia are necessary, use short acting intermittent agents, including fentanyl (1- 2 mcg/kg) and/or ketamine 0.5-1 mg/kg IV. Note that Propofol is not appropriate for long-term sedation in children but is a reasonable option for the first hours. Midazolam may also be used but can alter the neurologic exam for hours.

Primary Survey

- Airway control
  - Intubate for GCS of eight (8) or less or if unable to maintain stable airway.
    - Use rapid sequence intubation (RSI) Trauma Guideline
    - Assess GCS prior to administering sedation.
  - Maintain head of patient in neutral position, use rigid cervical collar (e.g. Aspen collar).
- Breathing
  - Maintain oxygen saturations at 93-97%
  - Maintain PCO_2 35-40 mmHg
  - Monitor end tidal CO_2 ($ETCO_2$) and obtain blood gases to correlate $ETCO_2$ to PCO_2 when indicated.
- Circulation
  - Consider early, transfusion first approach for circulation to minimize fluid overload from crystalloid
  - See Table 1 for minimum acceptable blood pressure by age group.
  - Avoid hypotension by ensuring adequate circulating blood volume using isotonic fluid (Normal Saline) or Trauma Packed red blood cell (PRBC) units as indicated.
  - Avoid hypotonic fluids as they exacerbate brain swelling.
  - May use pressor support once intravascular volume has been repleted.
  - Once euvolemia is attained, use Normal Saline (avoid hypotonic fluids) at age-appropriate maintenance intravenous (IV) rate.

Secondary Survey:

- Full neurologic exam including cranial nerve exam
- Trauma labs and x-rays per protocol, including electrolytes, glucose, ionized calcium, full CBC, and PT/PTT
- Obtain head computed tomography (CT) and other indicated imaging. STAT upload prior imaging if available
- If head of bed elevation is preferred, utilize reverse Trendelenburg (Revere T) positioning rather than just raising the head of the bed until thoracic spine cleared. Place Foley and orogastric tube (OG) unless contraindicated. Establish adequate IV access. Obtain CVL when indicated.

Neuroprotective Measures

Glucose Management

See Glycemic Guidelines: Critical Care for Patients 6 Months of Age and Older or Glycemic Guidelines: Critical Care for Patients Less than 6 Months of Age)

- Check serum glucose measurements on admission to PICU and minimum every 6 hours for first 48 hours
- Maintain serum blood glucose 80-180 mg/dL. Persistent hyperglycemia (greater than 180 mg/dL) and severe hypoglycemia (less than 40 mg/dL) are associated with increased mortality/worse neurological outcome.
- Avoid bolus insulin dose in trauma patients.

Ventilation

- Goal PCO_2 of 35-40 mmHg
- Monitor end-tidal CO_2 ($ETCO_2$).
- Obtain blood gases to correlate $ETCO_2$ with PCO_2 as indicated.
- Aggressive, rapid hyperventilation must be reserved for acute ICP crisis as adjunct with therapy escalation. Effect is temporary (less than 30 min), and rebound ICP elevation will occur with normalization of CO_2.

Seizures

- Seizure prophylaxis with levetiracetam 10 mg/kg BID x 7 days (max dose 1 g BID) should be administered to all severe TBI patients of all ages.
- Seizure monitoring:
  - Initiate EEG as early as feasible to evaluate for subclinical seizures, encephalopathy and reactivity. Seizures are common in patients with TBI.
  - For all patients with TBI admitted to the PICU, monitor with EEG for a minimum of 24 hours, or longer if clinically indicated.
    - Infants and patients with suspected abusive head trauma have a high risk for seizures and may benefit from prolonged monitoring of 48-72 hours. (See Special Considerations for Suspected Abusive Head Trauma)
    - GCS is an unreliable marker of the risk for seizures in children less than 2.5 years of age.
  - If the patient develops seizures, discuss treatment options with the Neurocritical Care Consult team at **Anschutz** or the Neurology team at **Colorado Springs**. Reference the Status Epilepticus Clinical Pathway as needed.

Sedation/Analgesia

- Provide analgesia and sedation to achieve a COMFORT Pain Score of 17-24 and a Richmond Agitation and Sedation Score (RASS) of -1, unless deep sedation is instituted for treatment of elevated ICP. If Deep sedation is needed to manage elevated ICP, then change administration instructions within analgesia and sedation order to reflect new COMFORT and RASS goals.
- Initial dosing of sedative continuous infusions:
  - Titrate sedative continuous infusions, including fentanyl, midazolam, and dexmedetomidine (be careful with dexmedetomidine in first 72 hours).

Indications for ICP Monitoring

The decision to monitor ICP is based on Glasgow Coma Score (GCS), CT scan findings, and clinical scenario at the discretion of the on-call neurosurgery attending.

- Strongly consider an ICP monitor in patients with GCS of eight (8) or less after initial resuscitation, especially if CT scan shows mass lesions (e.g. hematoma, edema), effaced basilar cisterns, or diffuse edema.
  - An ICP monitor may be placed in the setting of a borderline GCS when neurologic exam is unavailable for a prolonged period of time, e.g. emergent non-cranial surgery.

- For those going to operating room for removal of an intracranial mass (bleed), the need for monitoring will be assessed at surgery.
- The decision for or against the placement of an ICP monitoring device should be communicated by the neurosurgery attending to the trauma service and PICU attendings as well as their level of concern for anticipated ICP elevations and threshold for interventions (i.e. ICP, exam changes, EVD output).
- External ventricular drainage is preferred in cases when ventricles are deemed adequate without significant anatomical distortion, are enlarged or where CSF diversion is likely to be beneficial for ICP control.
- If GCS is marginal (9-13), and ICP monitor is not placed, follow exam with minimum necessary sedation/analgesia.
- GCS is assessed hourly by ICU nursing staff, with any decline in exam communicated to the PICU provider who will communicate with the neurosurgical services. Subacute development of elevated ICP with need for medical or surgical interventions is possible from ongoing brain swelling.
- If signs of herniation are present, consider giving hypertonic saline 3% (0.5 mEq/mL Na+) (5 mL/kg) or mannitol (1 gm/kg IV) or mild hyperventilation ($ETCO_2$ 32-35) while monitor is being placed.

THERAPEUTICS

Treatment of Elevated ICP

- Treatments are initiated for intracranial hypertension as defined by elevated ICP. Table 1 defines threshold values for treatment by age group. ICP units are mmHg (20 cm H_20 = 14.7 mmHg).
- Treat if ICP is above stated values. Treat Cerebral perfusion pressure (CPP) only when ICP cannot be controlled.

Table 1: Age Appropriate Pressure Ranges

Age	MAP (mmHg)	ICP (mmHg)	ICP Treatment Threshold
0-23 months	50-70	Less than or equal to15	Greater than or equal to 20
2-5 years	45-65	Less than or equal to 15	Greater than or equal to 20
6-8 years	65-85	Less than or equal to 20	Greater than or equal to 20
Greater than or equal to 9 years	70-95	Less than or equal to 20	Greater than or equal to 20

Mean Arterial Pressure (MAP)

- Elevate head of bed to 30 degrees – This is done in moderate to severe TBI patients.
- Check that cervical collar is loose enough to allow jugular venous return (able to easily slip a finger between collar and neck).
- Comfort sedation – Sedate as needed to a Richmond Agitation and Sedation Score (RASS) of -1. Short-acting agents are preferred. All intubated patients should receive comfort sedation.
- Cerebral spinal fluid (CSF) diversion – open external ventricular drain (EVD) if clamped and notify the PICU provider who will notify neurosurgery.
    - Consider placing an EVD or replacement of ICP monitor with EVD if ICP becomes refractory unless ventricles are slit-like or casted with blood

Hyperosmolar Therapy

- Hypertonic Saline 3% (0.5 mEq/mL Na+) is the first-line osmotic in any patient who is not fluid overloaded.
    - Administer a bolus of 5 mL/kg IV over 15 minutes for acutely elevated ICP.
    - Infuse 0.1 - 1 mL/kg/hour continuously for maintenance of ICP control.
    - Monitor serum chloride levels and for AKI while on hypertonic therapy (caution if greater than 125 mEq/L)
- Check serum sodium and osmolality every 4 hours while actively administering hyperosmolar therapy.
    - If sodium is greater than 165, be cautious and carefully consider administration of hypertonic saline.

- If limitation of total fluid volume is required (eg. in a patient receiving large amounts of fluid from drips and antibiotics), 12% (2 mEq/mL Na+) or 23.4% (4 mEq/mL Na+) saline solution may be substituted for 3% (0.5 mEq/mL Na+)

Hypertonic Saline %	Hypertonic Sodium Concentration	Recommended Dose	Max Dose Volume	Expected increase in serum sodium
3%	0.5 mEq/mL	5 mL/kg	234 mL	5 mEq/mL
12%	2 mEq/mL	1 mL/kg	60 mL	5 mEq/mL
23.4%	4 mEq/mL	0.5 mL/kg	30 mL	5 mEq/mL

- Mannitol
  - Consider mannitol if:
    - Hypertonic saline is not immediately available.
    - Patient is fluid overloaded.
    - ICP does not respond to initial hypertonic saline (HTS) bolus.
    - Mannitol should be used with caution if serum OSM is greater than 340.
  - Dosing: Refer to Formulary
  - Check serum osmolality (OSM) and calculated OSM prior to repeat bolus after infusion. If OSM gap is greater than 10 mmol, would not administer more mannitol since it is still circulating.
  - Osmolality (OSM) = (2 × Na^+) + (glucose ÷ 18) + (BUN ÷ 3); OSM gap = Serum OSM – Calculated OSM

Cerebral hypoperfusion

The below therapies are instituted in the following order when ICP cannot be controlled and CPP is low as defined by Table 1. They may also be considered when ICP is normal but mean arterial pressure (MAP) is low. Cerebral perfusion pressure (CPP) is calculated as follows: CPP=MAP-ICP.

- Bolus IV fluid – Normal saline, colloid, or blood.
- Repeat boluses to maintain euvolemia
- Norepinephrine– Titrate to goal cerebral perfusion pressure (CPP)
- Additional pressors as necessary– Titrate to goal cerebral perfusion pressure (CPP)

Sedation

Comfort sedation:

- Richmond Agitation and Sedation Score (RASS) less than or equal to –1 Comfort score 17-24
- With a goal of preserving a neurologic exam and safety for the patient
- Evaluate responsiveness to sedation boluses given for ICP as additional sedation may not be beneficial if there are no clinical signs of responsiveness to additional boluses

Deep Sedation:

- May be used concurrently with hyperosmolar therapy or prior to hyperosmolar therapy, according to provider discretion.
- Deep sedation for control of ICP refractory to osmotic therapy. Nursing maneuvers are minimized and neurologic exams should be minimized during deep sedation to minimize any stimulation to the patient.

Neuromuscular blockade

- Add neuromuscular blockade if ICP is refractory to sedation.
- Rocuronium /cisatracurium: Refer to formulary

- Titrate infusion to maintain ICP within goal range. Monitor paralysis with train of four with maximal therapy being reached when there is either ICP control or an absence of a train of four twitches. Other neuromuscular blockers may be used if indicated.
- Institute EEG monitoring when neuromuscular blockade is ongoing.

Sedation and neuromuscular blockade may acutely raise pCO_2 (and hence ICP) if patient has been over-breathing the ventilator prior to administration. End Tidal CO_2 ($ETCO_2$) monitoring diagnoses this and allows appropriate monitoring of ventilator changes.

Second-line ICP therapies

- Pentobarbital Coma
  - Consider in severe, non-lateralized, potentially salvageable cases.
  - Initial bolus of 10 mg/kg bolus over 30 min (can use a smaller bolus of 3-5mg/kg or slower infusion rate if hypotension develops).
    - Follow the initial bolus with 5 mg/kg/hr of pentobarbital for 3 hours
    - Continue pentobarbital infusion at 1 mg/kg/hr
  - Titrate to ICP effect and consider monitoring with continuous EEG monitoring with a target of 90% suppression (or a 1 second burst per 10 seconds of suppression) as a maximal therapy.
  - Close blood pressure monitoring will be needed. Order pressors to bedside prior to administration of pentobarbital bolus.
  - Monitor for pancreatitis (lipase every 3 days) and infection (daily blood cultures).

Decompressive Craniectomy

- PICU attending and neurosurgery attending discussion of indication for decompressive craniectomy:
  - Consider in lateralized cases or bifrontal craniectomy in non-lateralized cases with some likelihood of survival

Order of ICP Therapy weaning

- Normocapnia
- Barbiturate withdrawal as tolerated (ICP/ CPP)
- Paralytic withdrawal as tolerated (ICP/CPP)
- Sedation withdrawal as tolerated (Opiate/benzodiazepine as indicated to prevent withdrawal symptoms)
- Normalize serum sodium and osmolarity

Target Temperature

- Target temperature therapy is not recommended prophylactically but can be considered for ICP targeted therapy in refractory cases to moderate hypothermia (32-33° Celsius)

SYSTEMIC MANAGEMENT OF PATIENTS WITH MODERATE/SEVERE BRAIN INJURY

Nutrition

- Traumatic brain injury is associated with significant elevation in mean energy expenditure above predicted levels.
  - Institute nutrition (enteral preferred) within 72 hours of injury
    - Parenteral nutrition may be delayed up to one week in compromised patients

    Nutrition consult to assist in determining optimal volume and content of feeds/TPNPICU Nutrition Guidelines:

    - PICU Enteral Nutrition Guideline

- PICU Parenteral Nutrition Guideline

Venous Thromboembolism (VTE) prophylaxis and Treatment:

Due to the complexity of the Moderate/Severe TBI population please use the following VTE prophylaxis recommendations. ***Do not*** use the standard VTE Prevention clinical pathway recommendations for these patients.

Prophylaxis:

For VTE prophylaxis in TBI there are special consideration please see the VTE prophylaxis algorithm

Treatment:

The risk: benefit ratio of pharmacologic treatment of a documented venous thromboses, regardless of location (superficial vs deep DVT), is poorly defined for TBI patients and **management decisions should be multidisciplinary between the involved surgical, critical care, and hematology services.**

- Any intracranial hemorrhage is a *relative* contraindication to treatment-dose anticoagulation
- Any intracranial foreign body (external ventricular drain (EVD), ICP monitor) should be considered a relative contraindication to treatment-dose anticoagulation given an increased risk of associated hemorrhage in the acute post traumatic period. Multidisciplinary discussion is highly recommended.
- If pharmacologic treatment is deemed necessary in a patient with intracranial hemorrhage, strong consideration should be given to the following approaches:
  - Use a standard heparin infusion, without loading dose.
  - Target lower heparin assay levels (0.2-0.3 U/mL) for 2-4 days before escalating to full treatment dose
  - Repeat brain imaging before escalating to full treatment doses of heparin and/or transitioning to enoxaparin.

Blood Products and Coagulopathy

- Monitor and correct coagulopathy, as clinically indicated, in the initial 48 hours following injury
- Consider thromboelastography (TEG) as an adjunct lab to inform decisions regarding transfusion
- Platelet transfusion if platelets are > 100K may not provide benefit
- If intracranial pressure monitoring is warranted, consider platelet transfusion if platelets are < 100K
- If intracranial pressure monitoring is warranted, fresh frozen plasma may not provide benefit if INR is < 1.6

Rehabilitation

- Consult Physical Medicine & Rehabilitation (PM&R) for patients that have stabilized or have been hospitalized for greater than 5 days
- Consult PT/OT upon admission for early passive range of motion, bracing & splinting, and out of bed when appropriate.
- Consult speech therapy when patient stabilized or have been hospitalized for greater than 5 days to assist with assessing swallow abilities and communication even while intubated.
- Consult rehab neuropsychology when PM&R is consulted to assist with TBI education, coping with rehab process and adjustment to cognitive changes.
  - **Colorado Springs consideration:** If the patient is assessed by the on staff rehabilitation psychiatrist and it is determined that a neuropsychologist is needed, consult the Anschutz team to discuss treatment and/or transfer options

SPECIAL CONSIDERATIONS FOR SUSPECTED ABUSIVE HEAD TRAUMA

For Children less than 2.5 years of age

In children less than 2.5 years of age with concerns for or suspected abusive head trauma who:

- Present with seizures, apnea, sleepiness or irritability
- AND Have intracranial hemorrhage (subdural, subarachnoid, intraventricular or intraparenchymal hemorrhage) on initial imaging

Due to 1) the difficulty assessing mental status in young children, 2) unreliability of GCS in stratifying the severity of injury and 3) an increased risk of seizures (including clinical and subclinical seizures that may require ICU care) children meeting the above criteria should be:

- Admitted to the PICU for 24-48 hours
- Placed on continuous EEG for 72 hours (including after transfer from the ICU if less than 72 hours). Cessation of cEEG between 48 - 72 hours at the discretion of the neurology/neurocritical care team.

For all children with suspected abusive head trauma

EEG

Consider prolonged EEG monitoring (48-72 hours), since the majority of patients with abusive head trauma will have subclinical seizures which may be present on admission or delayed 24-72 hours.

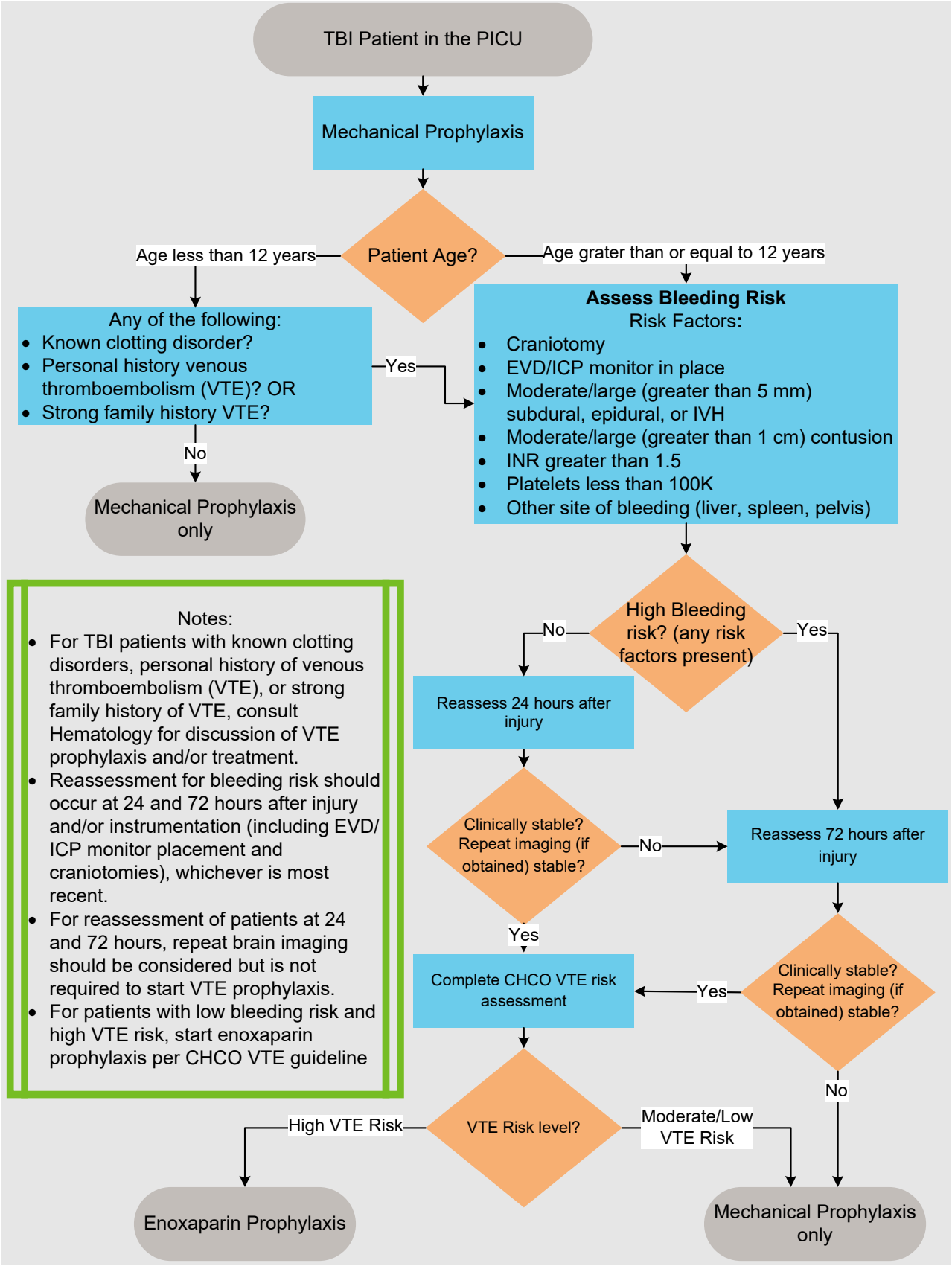
MRI Imaging

Cases of suspected abusive head trauma may be of unknown timing and mechanism. As a result, they warrant aggressive monitoring and oftentimes further imaging. Definitive MRI brain imaging should be performed no earlier than 48 hours after admission and preferably 72 hours after admission, but no later than 7 days following admission. The order should be for: “MRI brain with and without contrast, with venography”. Also request “MRI cervical spine without contrast.” Additional MRIs may be obtained outside the 72 hour-7 day window to assist with medical management, as needed.

Appendix A: Overview of Richmond Agitation and Sedation Score (RASS)

Score	Term	Description
+4	Combative	Overtly combative or violent; immediate danger to staff
+3	Very agitated	Pulls on or removes tube(s) or catheter(s) or has aggressive behavior toward staff
+2	Agitated	Frequent non-purposeful movement or patient-ventilator dyssynchrony
+1	Restless	Anxious or apprehensive bust movements not aggressive or vigorous
0	Alert and calm	
-1	Drowsy	Not fully alert, but has sustained (more than 10 seconds) awakening, with eye contact, to voice
-2	Light sedation	Briefly (less than 10 seconds) awakens with eye contact to voice
-3	Moderate sedation	Any movement (but no eye contact) to voice
-4	Deep sedation	No response to voice, but any movement to physical stimulation
-5	Unarousable	No response to voice or physical stimulation

Appendix B: VTE Prophylaxis for TBI



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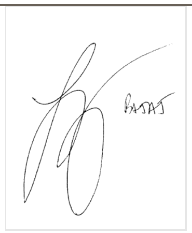
CLINICAL IMPROVEMENT TEAM MEMBERS

Derek Samples, MD | Neurosurgery
Matthew Mayer, MD | Physical Medicine & Rehabilitation
Lauren Desmarais, MD | Physical Medicine & Rehabilitation
Ricka Messer, MD, PhD | Neurology
Kari Fontenot, RN | Emergency Medicine
Johnny Weatherford, RN | Emergency Medicine
Elizabeth Diaz, RN | Critical Care
Amanda Carmean, MD | Critical Care
Lindsey Rowe, RN | Critical Care
Sharon Gordon, PharmD | Clinical Pharmacist Specialist

APPROVED BY

Clinical Pathways and Measures Committee – November 27, 2023
Pharmacy & Therapeutics Committee – December 7, 2023
Anschutz Trauma Committee: January 30, 2024
Colorado Springs Trauma Committee: January 30, 2024

MANUAL/DEPARTMENT	Clinical Pathways/Quality
ORIGINATION DATE	March 13, 2018
LAST DATE OF REVIEW OR REVISION	November 27, 2023
COLORADO SPRINGS REVIEW BY	 Michael DiStefano, MD Chief Medical Officer, Colorado Springs
APPROVED BY	 Lalit Bajaj, MD, MPH Medical Director, Clinical Effectiveness

REVIEW | REVISION SCHEDULE

Scheduled for full review on November 27, 2027

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