Protocol for Management of Traumatic Brain Injury in Children with GCS < 8.

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A. Managing Patients Without Intracranial Pressure (ICP) Monitoring

- Spinal precautions:
  - head of bed elevated 20-30° with head in neutral midline position, maintaining spinal precautions
  - semi-rigid cervical collar (Aspen) maintained until cervical spine cleared (see http://portal/sites/CriticalCarePrg/Documents/C%20Spine%20Clearance.pdf

- Neurologic Monitoring:
  - clinical – obtain baseline neurologic examination without muscle relaxants
  - routine nursing neurovitals assessment hourly

· Hemodynamic support

  - arterial line - for routine indications
  - maintain mean arterial pressure upper end of normal based on normal age range (see table 1)

§ inotropes as required/fluids as required

- Ventilation/oxygenation:
  - maintain $PaCO_2$ 35-40mmHg
  - maintain arterial saturations >94%

- Fluid and electrolytes:
  - D5W 0.9%NaCl at 70% maintenance
  - monitor serum electrolytes and blood gases every 6 hours for 48 hours. Frequency to be reviewed thereafter
  - if cerebral salt wasting is thought to contribute to hyponatremia, consider 3% saline infusion
  - normoglycemia (maintain serum glucose 5-8mmol/L)

- Temperature control:
  - monitor core temperature - esophageal
  - regular acetaminophen 15mg/kg every 6 hours NG/NJ – review every 24 hours
  - normothermia 36-36.5C (external cooling if necessary, to avoid hyperthermia)
    - consider neuromuscular blockade to facilitate temperature control

- Sedation/analgesia:
  - every effort should be made to allow clinical examination each morning by the medical and nursing team by reducing sedation or discontinuing muscle relaxants
  - follow routine PICU nursing procedure using pain/sedation algorithm to manage pain and sedation based upon routine scoring
    - initiate analgesia and sedation with morphine infusion 10-40 mcgs/kg/hour and midazolam infusion 50-150 mcgs/kg/hour

- Seizure prevention:
  - Prophylactic Levetiracetam (Keppra) 10mg/kg NG/PO every 12 hours for 7 days.
  - for clinical seizures, give a loading dose of Levetiracetam (20mg/kg IV)
  - consider EEG within first 36 hours of admission
  - continuous EEG monitoring is recommended if resources are available

- Nutrition:
  - commence within 24 hours of admission. If gastric paresis persists beyond 48 hours, a jejunal

feeding tube should be placed (see PICU Transpyloric Feeding Tube Insertion Policy)
    - close monitoring required during initiation of enteral feeds to avoid hyponatremia (i.e. continued q6 hourly serum electrolyte measurement)

- Pressure ulcer prevention:
    - assess patient for risk of pressure ulcer development as per unit standards
    - implement standard pressure injury prevention interventions
    - patients identified as high or very high risk implement additional precautions (S.K.I.N)

· Patient mobilization[KJ[1] :
    - important to rotate patients from side to side for respiratory management and pressure sore prevention – special care may be required for patients with unstable ICP/unstable C spine.
    - physiotherapy for passive range of motion/other activities in discussion with neurosurgery

- Consults:
    - Neurology for consideration of continuous EEG monitoring
    - Physiotherapy and occupational therapy within 24 hours
    - Orthopedic surgery
        - cervical spine clearance
        - for consideration of botox injections to reduce spasticity
    - Sunnyhill (via Physiotherapist or Rehabilitation Medicine on-call)
    - Canuck Place
    - Home trach and vent team if tracheostomy

B. **Managing Patients With ICP Monitoring**

Definition of Elevated ICP – pressure > 20cmH_20 for greater than 5 minutes.
(It is not uncommon for ICP to increase incrementally for 2-3 days before resolving. Depending on the clinical condition of the patient and follow-up CT scans, the actual daily ICP threshold for each patient may change and should be reassessed daily with a collaborative discussion between the neurosurgical and medical team.)

- Monitoring:
    - arterial line - for routine indications
    - maintain mean arterial pressure upper end of normal based on normal age range
    - EVD and arterial line transducer set to level of tragus (see Appendix 1)
    - CVS parameters – normotension based on age (see Appendix)
        - Cerebral perfusion pressure (CPP) management (MAP-ICP):
            - 0-6 year old: maintain CPP > 40mmHg
            - 6 year old to adult: maintain CPP > 40-50mmHg

Note: measures to improve CPP typically include decreasing ICP, fluid resuscitation, and maintaining normal MAP (see Appendix 2)

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    - D5W 0.9%NaCl at 70% maintenance
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    - if cerebral salt wasting is thought to contribute to hyponatremia, consider 3% saline infusion
    - normoglycemia (maintain serum glucose 5-8mmol/L)

- Temperature control:[KM2]
    - maintain normothermia (see below)
    - regular acetaminophen 15mg/kg every 6 hours NG/NJ – review every 24 hours
    - 'CritiCool' cooling blanket to maintain temperature 36-36.5°C (90% of head injured patients develop fever)
    - prevent shivering during active cooling with muscle relaxant
    - persistent fever (see Appendix

- Sedation/analgesia:
    - every effort should be made to allow clinical examination each morning by the medical and nursing team by reducing sedation or discontinuing muscle relaxants
    - follow routine PICU nursing procedure using pain/sedation algorithm to manage pain and sedation based upon routine scoring
    - initiate analgesia and sedation with morphine infusion 10-40 mcgs/kg/hour and midazolam infusion 50-150 mcgs/kg/hour

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- Patient mobilization:
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    - physiotherapy for passive range of motion/other activities in discussion with neurosurgery

- ICP management:
    - check ABG/$ETCO_2$ to confirm ventilation (target $PaCO_2$ = 35-40 mm)
    - check sedation/analgesia scores
    - open EVD if present – allow to drain for 5 minutes
        - may be left open at the discretion of neurosurgery - PICU physician. If left open, the actual ICP is unknown – need to check every 15 minutes by turning the stopcock, especially if not draining.
    - hypertonic fluid bolus if persistently elevated
        - mannitol 0.5-1gm/kg IV (2.5-5mls/kg) over 10 minutes for sustained ICP increase (if serum Osmolarity is under 320)
        - 3% NaCl 2.5-5mls/kg over 5 minutes if serum Na < 140mmol/L
        - check electrolytes following bolus therapy
    - consider ongoing paralysis with rocuronium

- Refractory severe intracranial hypertension – additional therapies (each individual step should be discussed by the clinical team for each patient, balancing risks and benefits):

    - open EVD
        - may be left open at the discretion of neurosurgery - PICU physician. If left open, the actual ICP is unknown – need to check every 15 minutes, especially if not draining by turning the stopcock.
    - hypothermia 32-35 degrees C if the above measures fail, and prior to hyperventilation
    - controlled hyperventilation – to a $PaCO_2$ 30-35mmHg. More aggressive hyperventilation should only be performed with the guidance of a jugular venous catheter (see Appendices 2,3,4).
        - hypertensive therapy – optimizing CPP (cerebral perfusion pressure). If the ICP remains problematic and unresponsive to all of the above maneuvers, consideration should be given to increasing the systemic blood pressure. A central venous catheter is required for vasoactive infusions and CVP monitoring. An assessment of intravascular volume should exclude hypovolemia prior to initiating any vasoactive agent. Choices include dopamine, phenylephrine or noradrenaline, targeting a normal to high CPP.
        - lumbar drain – only after consultation with neurosurgery and discussion of risks with family
        - decompressive craniectomy – only after consultation with neurosurgery and discussion of risks with family

C. Management of Acute Neurological Deterioration with Acute Pupillary Dilation

- If patient has an EVD, open to drain:
    - if obstructed, flush distal system (i.e. away from the head, via the most proximal 3-way connector) in a sterile fashion, and if still obstructed, aspirate gently (with guidance from Neurosurgical team
    - if aspiration fails to unblock EVD, aseptically flush EVD with 0.5-1ml of 0.9%NaCl

- Hyperventilate with 100% O_2 if pupils remain dilated - intubate if not intubated

- Support the cerebral perfusion pressure with fluids and inotropes

- Elevate head of bed to 20-30 degrees

- Administer Mannitol 20% (1gm/kg - 5mls/kg - over 5 minutes) or hypertonic (3%) saline – 5 ml/kg over 5 minutes (note – Mannitol will often result in diuresis after 10-30minutes, and rarely can result in decreased blood pressure)

- Notify intensive care specialist-on-call

- Notify neurosurgeon-on-call

- Arrange urgent CT scan of head simultaneously with all of the above actions

D. Consideration of Endocrinopathy

In the context of TBI, panhypopituitarism should be considered. Specifically, if there is difficulty in maintaining vital functions (blood pressure), if a random cortisol is < 500 nmol/L, if another pituitary hormone deficiency is present or if the anatomical lesions suggest a hypothalamo-pituitary injury, a stress dose of hydrocortisone should be provided for 10 days until a proper assessment of the pituitary function can be performed (IV Hydrocortisone 30 mg/m^2/day divided in 4 doses).

In addition, patients with severe traumatic brain injury can also suffer other endocrine disorders including adrenocortical insufficiency, which can be challenging to diagnose.

Consultation with the BCCH Endocrinology Service can further clarify management of post-traumatic endocrinopathy.

Appendix 1. Management of EVD's

- Transducer maintained at level of tragus as closed system
- No prophylactic antibiotics
- No daily routine CSF cultures

· Reduce breaking into the sterile circuit – if you need to, refer to External Ventricular Drain (EVD) and Lumbar Drainage Device (LDD) Policy:http://policyandorders.cw.bc.ca/resourcegallery/Documents/BC%20Children's%20Hospital/CC%2013%2001%20(NE009014)%20External%20Ventricular%20Drainage_JAN%202016%20FINAL[6204][8862] pdf to reduce contaminating the drain and/or CSF.

Appendix 2. Normal Cerebral Perfusion Pressure

The general goal of the monitored child is to maintain ICP < 20mmHg. Younger children have a lower normal ICP and lower levels ICP at which to treat would need to be considered in individual cases. Normal CPP following a head

injury in children of different ages is unknown, and can only be estimated from what is known of normal values. Some children ***may*** require a higher than normal CPP for their age to maintain adequate cerebral blood flow. Keep in mind that autoregulation can be disrupted in the context of TBI, and physiology may behave unpredictably.

ICP is normally elevated in healthy patients by such maneuvers as coughing and turning, and is usually coincident with an elevation in blood pressure.
An elevated ICP becomes abnormal when:

- it is associated with a fall in cerebral perfusion pressure (CPP)
- remains elevated (>5 minutes) and becomes a plateau rather than a spike
- frequent and recurrent unstimulated spikes in pressure

Table 1: Normal Age Ranges for Systemic Arterial BP, ICP & CPP

AGE	70^{th}% mBP (mmHg)	75^{th}% sBP	ICP (mmHg)	Acceptable CPP
6 months	70	90	2	40
12 months	75	90	5	40
2 years	75	90	10	40
5 years	75	95	10	40
12 years	80	110	12	40-50
15 years	80	110	12	40-50

References

Haque IU et al. Analysis of the evidence for the lower limit of systolic and mean arterial pressure in children. DOI: 10.1097/01.PCC.0000257039.32593.DC Pediatr Crit Care Med 2007; 8:138 –144

Flynn JT, Kaelber DC, Baker-Smith CM, et al. Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents. Pediatrics. 017;140(3):e20171904

Roberts JS et al. Age-Based Percentiles of Measured Mean Arterial Pressure in Pediatric Patients in a Hospital Setting. Pediatr Crit Care Med 2020; 21:e759–e768

Suttipongkaset P et al. Blood Pressure Thresholds and Mortality in Pediatric Traumatic Brain Injury. Pediatrics. 2018;142(2):e20180594

Appendix 3: Guidelines for Optimization of CBF/CEO2/CPP and ICP

Normal cerebral oxygen extraction (CEO_2) in children is suspected to be ~ 35%. Cerebral global oligemia should be suspected if CEO_2 > 35% - regional oligemia may occur at lower levels.
Management options for the possible interactions of CEO_2, ICP and CPP include:

- Normal or low CEO_2, ICP, CPP: no specific therapy

- Normal CEO_2 + elevated ICP:
  - open EVD to drain CSF
  - 20% mannitol/3% NaCl (depending on serum sodium)
  - optimized hyperventilation
  - ?lumbar drain
  - ?barbiturates

- Elevated CEO_2 + normal ICP and CPP:
  - allow CO_2 to increase in small increments
  - if ICP rises with this maneuver, give 20% mannitol or 3% NaCl then follow the steps in (2) above

- Elevated CEO_2 + elevated ICP
  - 20% Mannitol/3% NaCl
  - ?lumbar drain
  - ?barbiturates

- Decreased CEO_2 + normal ICP/CPP
  - no specific therapy

- Decreased CEO_2 + elevated ICP
  - optimized hyperventilation +/- 20% mannitol/3% NaCl

Notes of Explanation:

- If CEO_2 > 35%, this implies either excessive oxygen consumption by the brain or inadequate oxygen delivery or inadequate blood flow to the brain. Hence interventions are required to either reduce oxygen consumption or increase blood flow.

- If CEO_2 < 25%, this implies that there is either a low oxygen consumption by the brain (very low extractions occur with the most severe injuries and brain death), or excessive cerebral blood flow.

- If there is an associated increased ICP, then interventions may be undertaken to reduce the excessive flow

in an attempt to reduce the ICP, but NOT at the expense of maintaining an adequate cerebral perfusion pressure (e.g., consider lowering the $PaCO_2$ in an effort to reduce CBF). Any intervention undertaken to manipulate blood flow should be monitored with a CEO_2 to ensure that the blood flow remains acceptable. If the CPP and ICP are reasonably controlled, and the CEO_2 is < 30%, there is no need to intervene for a CEO_2.

Appendix 4. Management of Jugular Venous Catheters

- Infuse 0.9% sodium chloride with 2 units Heparin/cc at 2 mls/hr on an intravenous infusion device (e.g., Alaris pump)
- Verify position of catheter with a lateral cervical spine x-ray of base of brain and vertebrae to assure correct position
- Measure cerebral oxygen extractions for acute changes in therapy (eg. hyperventilation); otherwise once a shift. $\{CEO_2 = 100 \times (SaO_2 - SjO_2)/SaO_2\}$

Collection of samples: aspirate very slowly to minimize risk of cross contamination of blood from non-cerebral sources

Appendix 5. Indications for CSF cultures from EVD

CSF cultures should be ordered and drawn if:

- Temperature - if the patient's core temperature is > 38.5C, the patient will be cultured for blood, urine, tracheal and CSF (including CSF cell count and differential). Empiric antibiotics will be commenced to cover most likely organism and source (e.g., if chest infection, cover chest organisms). No need for further daily CSF specimens unless specifically ordered by attending physician.

- Cloudy CSF – if CSF is cloudy send CSF specimen and commence antibiotics (vancomycin + cefotaxime)

- Patient in an induced hypothermic state - daily CSF cell count and differential, culture and gram stain from day 3, until the therapy has been discontinued

- Patient is on steroids (eg. patients with brain tumors) - daily CSF culture and gram stain from day 3, until the therapy has been discontinued

- Neurological condition of patient deteriorates unexpectedly (e.g., ICP becomes unstable) - CSF specimen collected as part of workup in searching for the cause.

NOTE: A CSF culture should always be taken in an *aseptic fashion* from the *most proximal port* to the patient. Refer to ICU Nursing Unit Policy: Obtaining a sample of cerebrospinal fluid from an external ventricular drainage system

References

https://braintrauma.org/guidelines/guidelines-for-the-management-of-severe-tbi-4th-ed#/

https://journals.lww.com/pccmjournal/fulltext/2019/03001/guidelines_for_the_management_of_pediatric_severe.1.aspx

[KJ[1]]I've forwarded this to Niamh, our PICU PT, as there was an ask from her to add in a mention for passive range of motion, and recommendations for other activities that could be completed on a bed rest patient requiring 'low stimulation'

[KM2]Consider: prevention of shivering while using active cooling