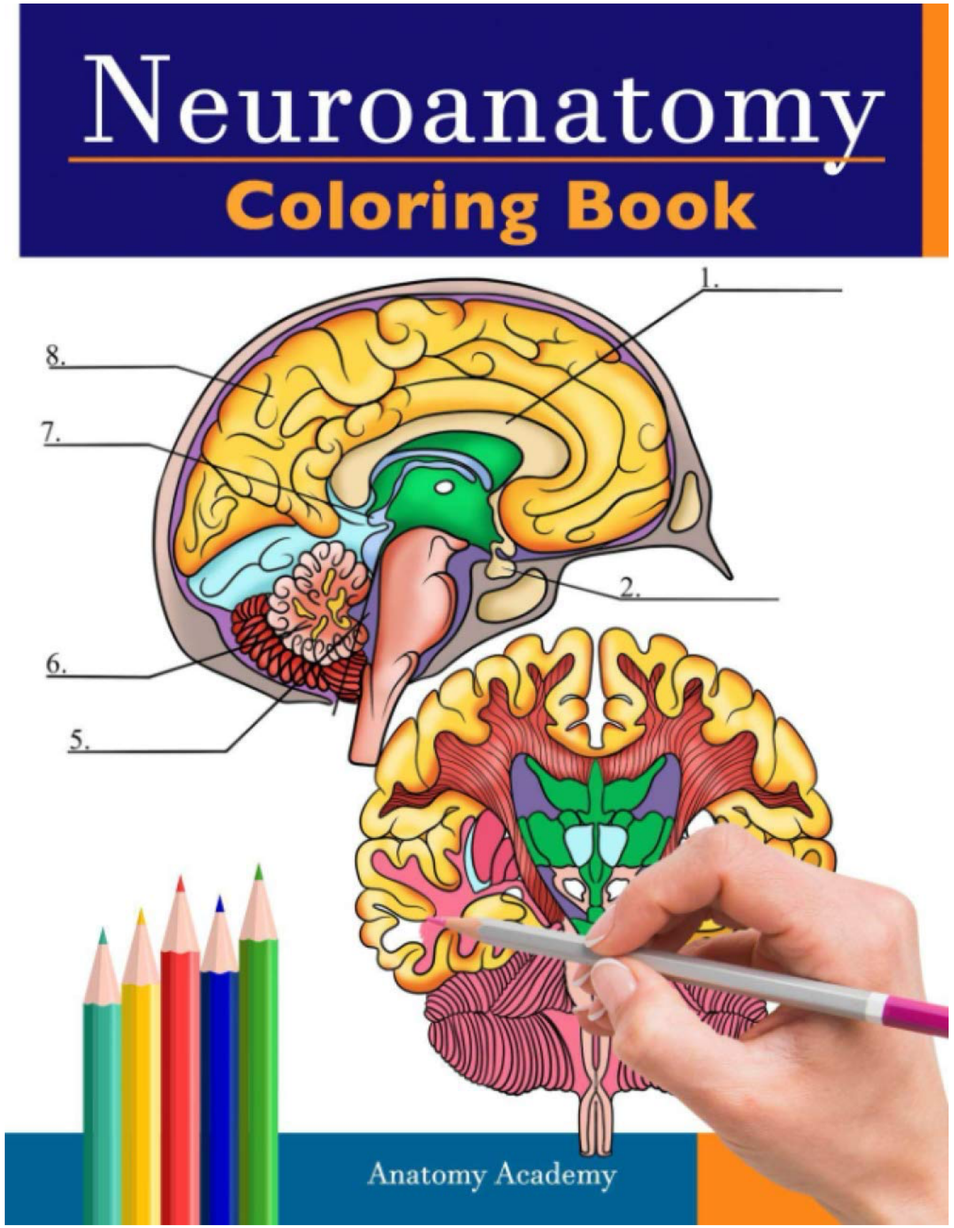
Neurosurgical Critical Care Topics in the Pediatric Patient

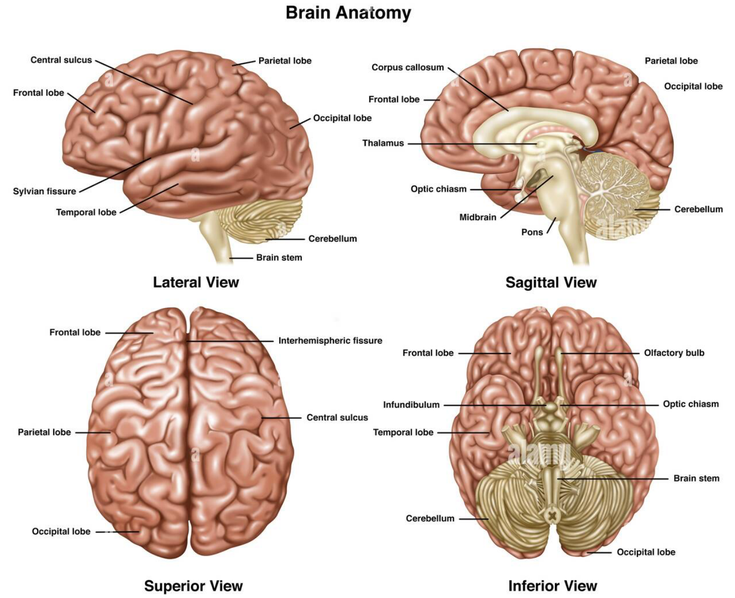
Thomas Ridder, MD FAANS
Pediatric Neurosurgery - Children's Hospital of Colorado - Colorado Springs

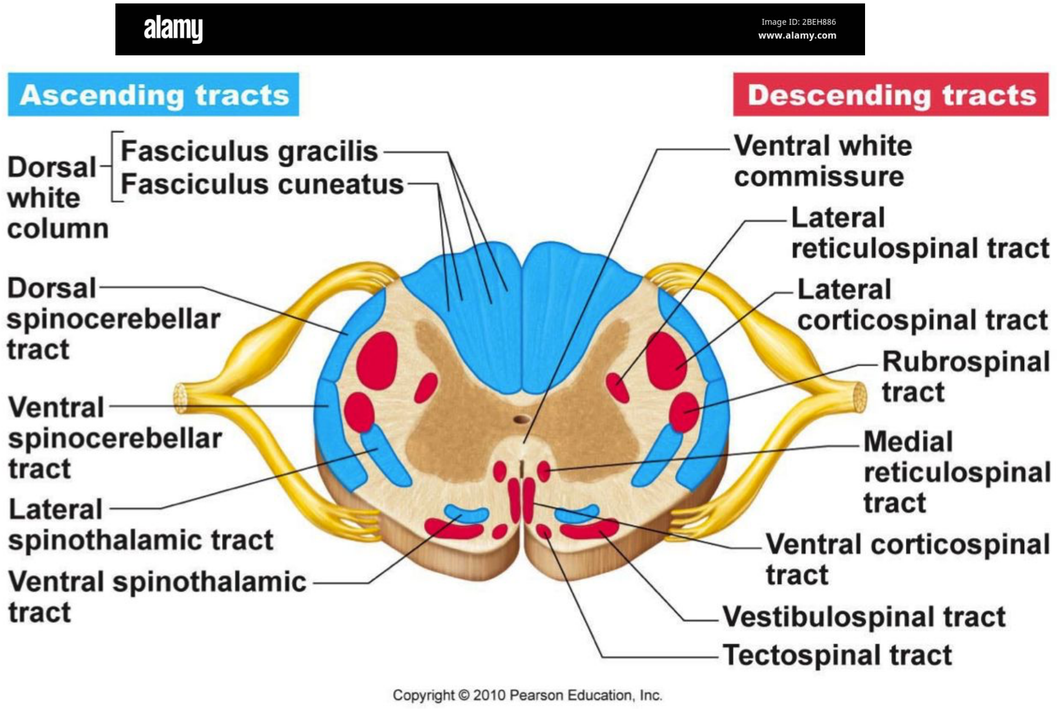
Disclosures : None



Objectives:

Discuss neurosurgical topics commonly seen in the care of a pediatric ICU patient





Disorders of Pediatric Neurocritical Care (PNCC)

TBI
Epidural, subdural, cerebral contusion, subarachnoid hemorrhage, diffuse axonal injury, penetrating TBI

Seizures and Status Epilepticus
Epilepsy, complex febrile seizures, secondary seizures to CNS injury (TBI, malignancy, infection)

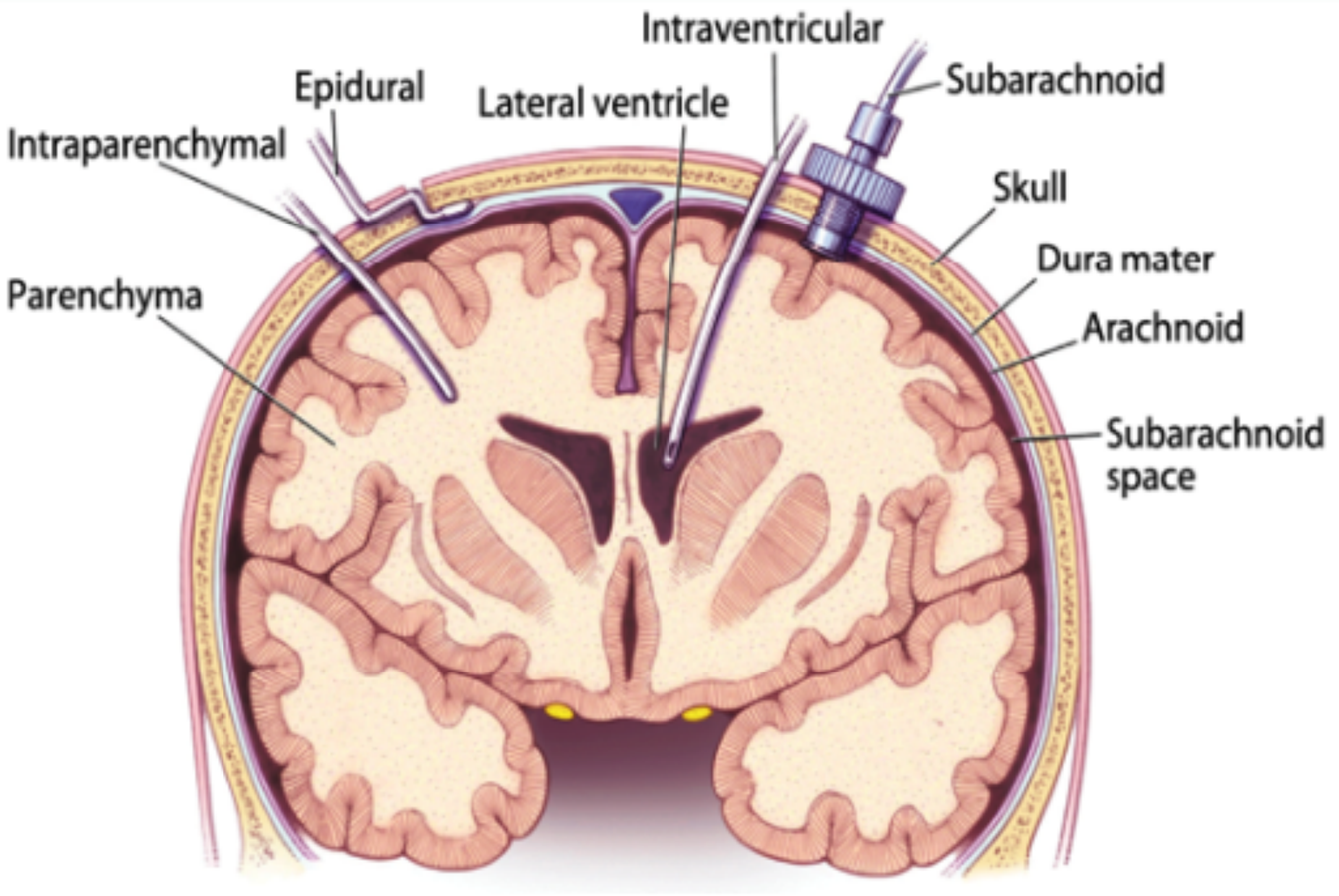
Ischemic Stroke
Sinus Venous thrombosis
Metabolic Stroke
Ruptured arteriovenous malformations
Infectious Encephalitis and Meningitis (bacteria, viral, fungal, mycobacterium)
Autoimmune encephalitis and encephalomyelitis (Post-infectious autoinflammation, ADEM)
Intracranial abscess and empyema
Cerebral Edema Secondary to Metabolic and Endocrine Diseases (diabetic ketoacidosis, ammonia, Na fluctuations, mitochondrial)
Hypoxic Ischemic Injury
Hydrocephalus
Intracranial neoplasms

PNCC Service History

- 1932 - Dr WE Dandy developed a post-operative neurosurgical unit at JH
- 1940-50s - polio epidemic led to hospitals opening critical care units in Europe and North America
- 1955 - 1st PICU opened in Sweden at Children’s Hospital of Goteberg
- Several different types of care models have emerged over the last few decades

Neuromonitoring

- Preventing secondary injury remains major goal of modern neurocritical care
- Hypotension, hypoglycemia, intracranial hypertension and seizures
- Physical Exam, imaging, EEG, ICP and brain oxygenation measurements



Physical Exam

- GCS 3-15 with modified scale for infants and small children. Not really validated outside of trauma patients and does not correlate with airway protective reflexes.
- FOUR Score (Full Outline of UnResponsiveness)* - eye, motor response, brainstem reflexes and respirations - comparable but not superior.

Glasgow Coma Scale		
Response	Scale	Score
Eye Opening Response	Eyes open spontaneously	4 Points
	Eyes open to verbal command, speech, or shout	3 Points
	Eyes open to pain (not applied to face)	2 Points
	No eye opening	1 Point
Verbal Response	Oriented	5 Points
	Confused conversation, but able to answer questions	4 Points
	Inappropriate responses, words discernible	3 Points
	Incomprehensible sounds or speech	2 Points
	No verbal response	1 Point
Motor Response	Obeys commands for movement	6 Points
	Purposeful movement to painful stimulus	5 Points
	Withdraws from pain	4 Points
	Abnormal (spastic) flexion, decorticate posture	3 Points
	Extensor (rigid) response, decerebrate posture	2 Points
	No motor response	1 Point
Minor Brain Injury = 13-15 points; **Moderate Brain Injury** = 9-12 points; **Severe Brain Injury** = 3-8 points		

FOUR Score

Eye Response
- 4= eyelids open or opened, tracking, or blinking to command
- 3= eyelids open but not tracking
- 2= eyelids closed but open to loud voice
- 1= eyelids closed but open to pain
- 0= eyelids remain closed with pain

Motor Response
- 4= thumbs-up, fist, or peace sign
- 3= localizing to pain
- 2= flexion response to pain
- 1= extension response to pain
- 0= no response to pain or generalized myoclonus status

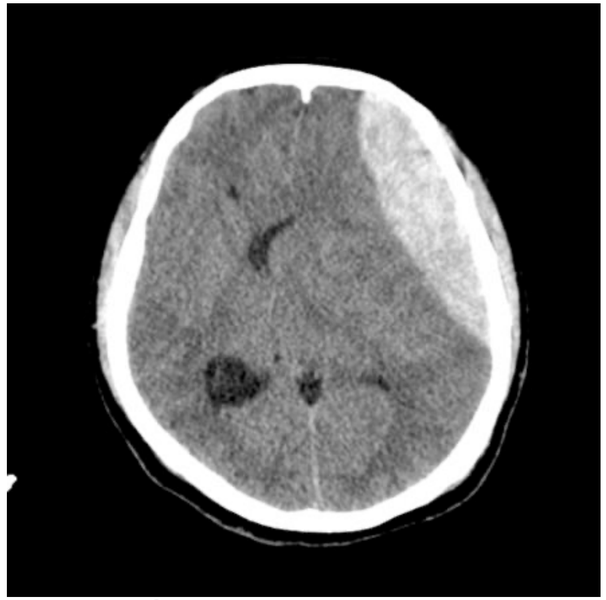
Brainstem Reflexes
- 4= pupillary and corneal reflexes present
- 3= one pupil wide and fixed
- 2= pupillary or corneal reflexes absent
- 1= pupillary and corneal reflexes absent
- 0= absent pupillary, corneal, and cough reflex

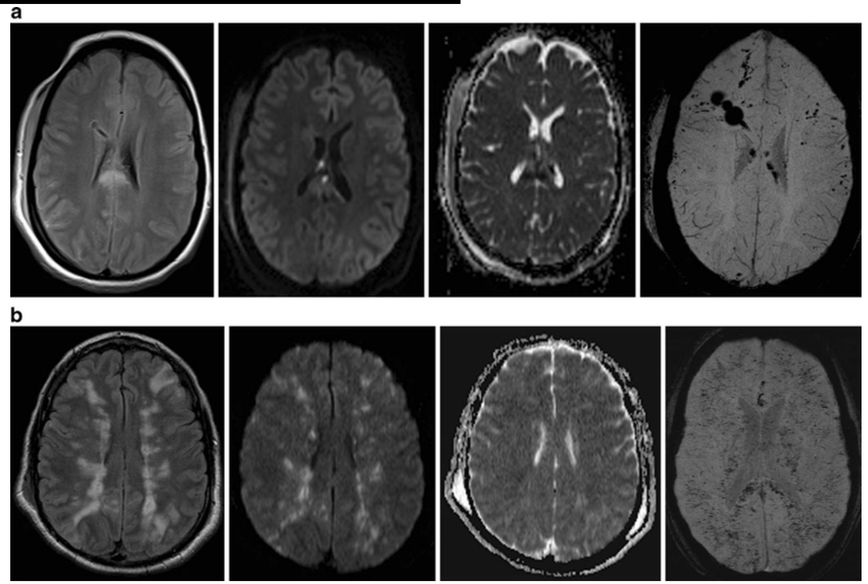
Respiration
- 4= not intubated, regular breathing pattern
- 3= not intubated, Cheyne-Stokes breathing pattern
- 2= not intubated, irregular breathing pattern
- 1= intubated, breathes above ventilator rate
- 0= intubated, breathes at ventilator rate or apnea

1. Czaikowski BL, Liang H, Stewart CT. A pediatric FOUR score coma scale: interrater reliability and predictive validity. J Neurosci Nurs. 2014 Apr;46(2):79-87. doi: 10.1097/JNN.0000000000000041. PMID: 24556655.

Imaging

- Physical Exam + GCS or FOUR Scores = > Decision for Neuro imaging
- CT - remains primary tool to detect neurologic emergencies yet concerns for radiation exposure and development of malignancy. Incidence of 1 new malignancy case for every 1,000 to 10,000 CT scans in children younger than 15 years of age.* Dose attenuation protocols exist now. Excellent for bony fractures and acute bleeding.
- MRI - fast sequence or rapid MRI with shorter scanner times. Excellent tool for hydrocephalus and repeat/follow-up neuro trauma imaging. Susceptibility and FLAIR (fluid attenuation inversion recovery) modes superior for acute hemorrhage, edema, DAI
- XR - Spinal alignment/instability, craniocervical injuries
- TCDs - TransCranial Dopplers to assess for auto regulation and vasospasm

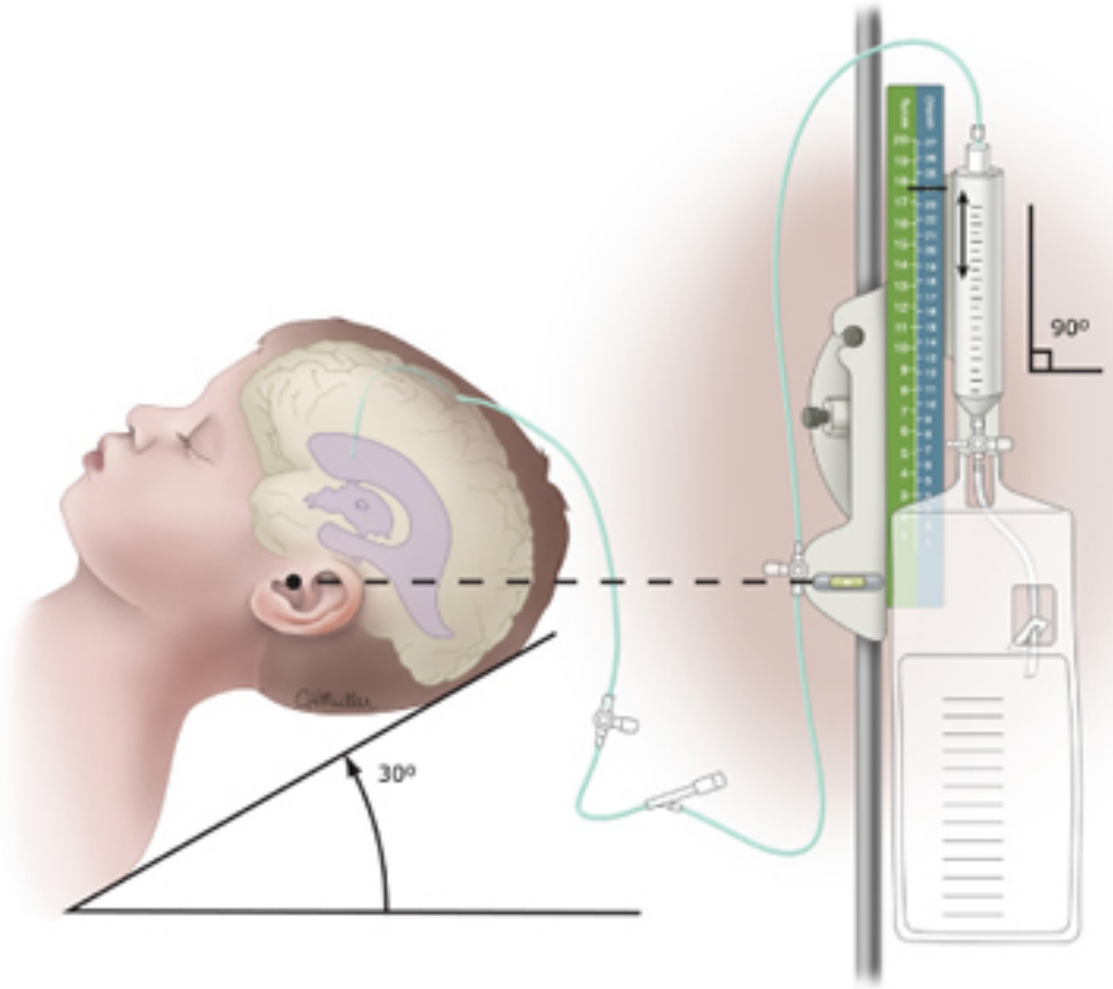




*Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, Feigelson HS, Roblin D, Flynn MJ, Vanneman N, Smith-Bindman R. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr. 2013 Aug 1;167(8):700-7. doi: 10.1001/jamapediatrics.2013.311. PMID: 23754213; PMCID: PMC3936795.

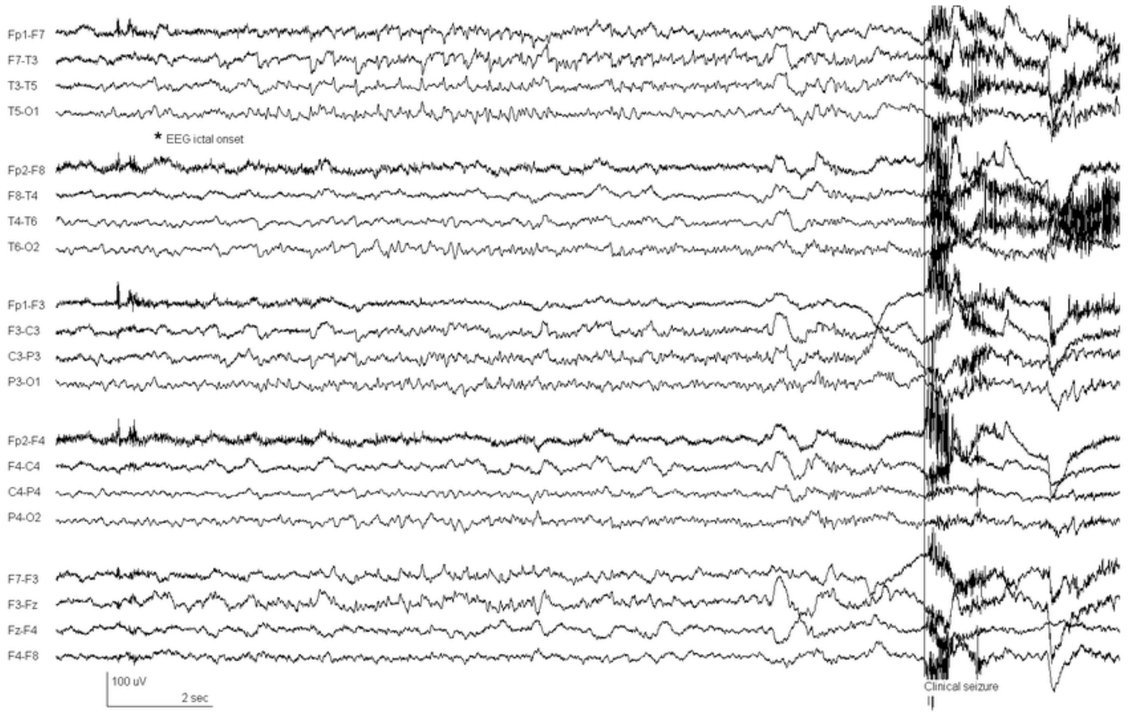
Cerebral Oximetry and Perfusion

- Jugular venous O2 (SjO2) - used to monitor global O2 extraction. Utility in PICU?
- NIRS - Near InfraRed Spectroscopy - sensor applied to forehead of patient with measurements of underlying cortical surface by filtering out overlying skin and subcutaneous tissue.
- Partial pressure of brain tissue - PbO2 - values < 10 mm Hg can be associated with unfavorable outcomes. Limitation is only selective to focal area of tissue.
- Cerebral perfusion pressure = MAP - ICP => CPP versus ICP driven therapies?



EEG

- Of children admitted to the hospital with a neurological diagnosis, more than 50% may have seizures as primary diagnosis
- Clinical vs. subclinical seizures
- After TBI, 12% of seizures occur within the first 7 days following injury with risks secondary to injury severity, age, and abusive head trauma.`
- Nearly 1/3 of children under 2 years of age with abusive head trauma will have subclinical seizures. Role of cEEG is vital for care and work-up

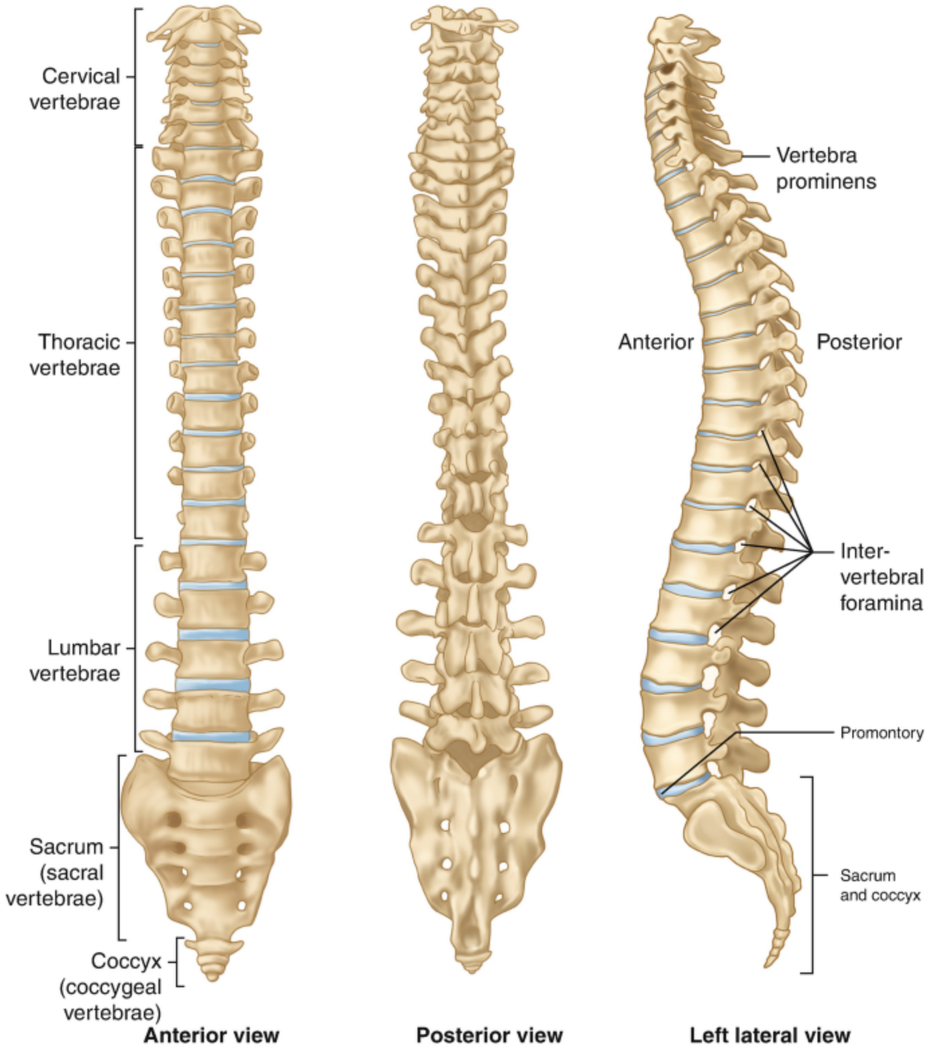


CNS Emergencies in PNCC

- Disorders of elevated ICP and compromised CPP - ideal ICP threshold for treatment in trauma patients. Shunt obstruction from underlying communicating or obstructive hydrocephalus
- Seizures and status epileptics - < 1 year old baby with abusive head trauma
- Cerebral ischemia from embolic and thrombotic stroke - much less common than traumatic or seizures. Estimated incidence of 1-2 cases per 100,000 per year.
- Infectious and non-infectious CNS inflammation
- Hypoxic injury - cardiac arrest, drowning, strangulation

Pediatric Spinal Trauma

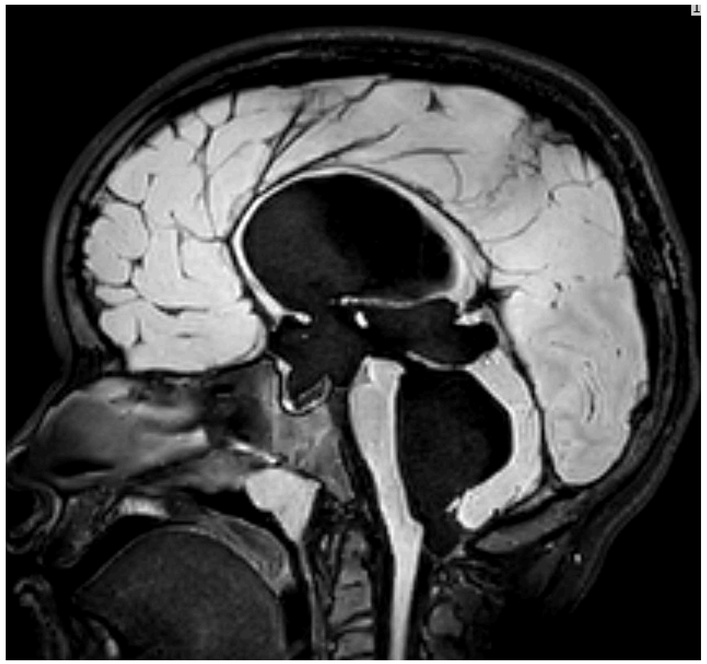
- Spinal fractures, ligamentous and spinal cord injuries
- SCI in pediatric population < 4% incidence of the overall SCI population. 17-30 years old remains highest (>50%). Higher risk of developing scoliosis long term
- Craniocervical injuries in younger children due to larger head size and surface area compared to body
- SCIWORA - sports injuries or Child abuse
- Bracing versus surgical intervention

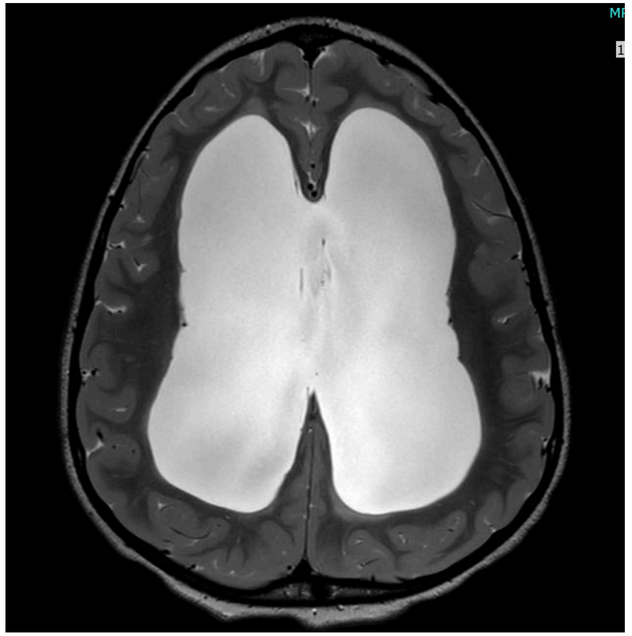


Case Examples

Case 1

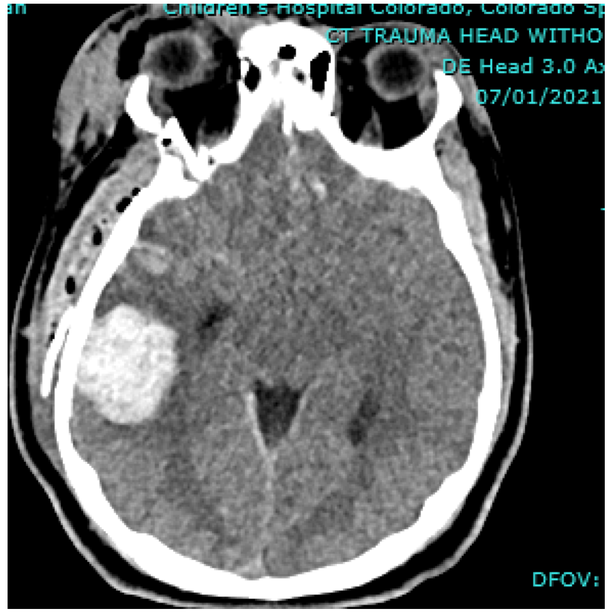
- 7 year old 1st grade boy who presents with several months of progressive ataxia, intermittent syncopal episodes, headaches, and hand tremors
- PE: Awake, macrocephalic with OFC 59 cm, cerebellar dysmetria, ataxia

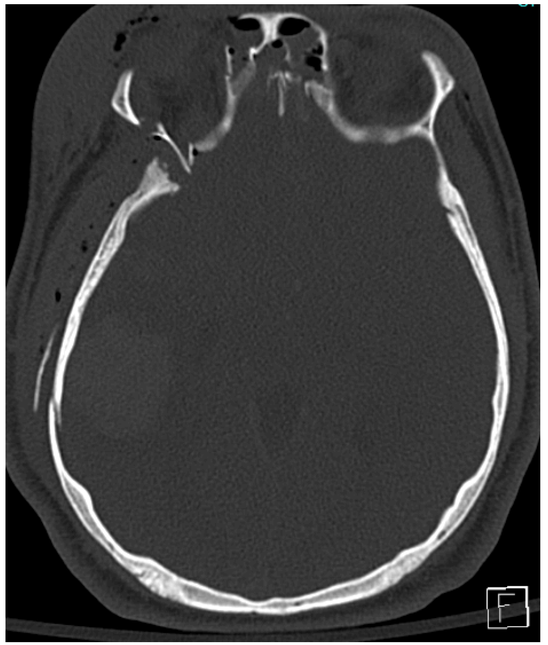


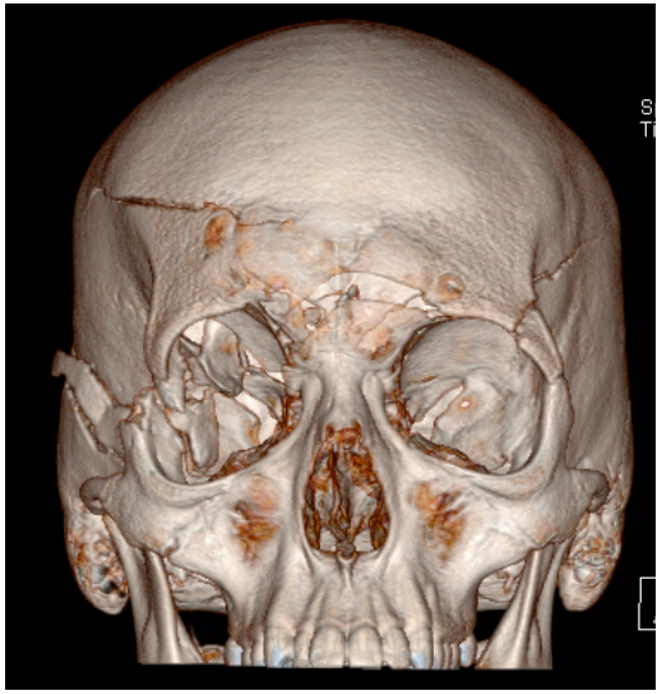


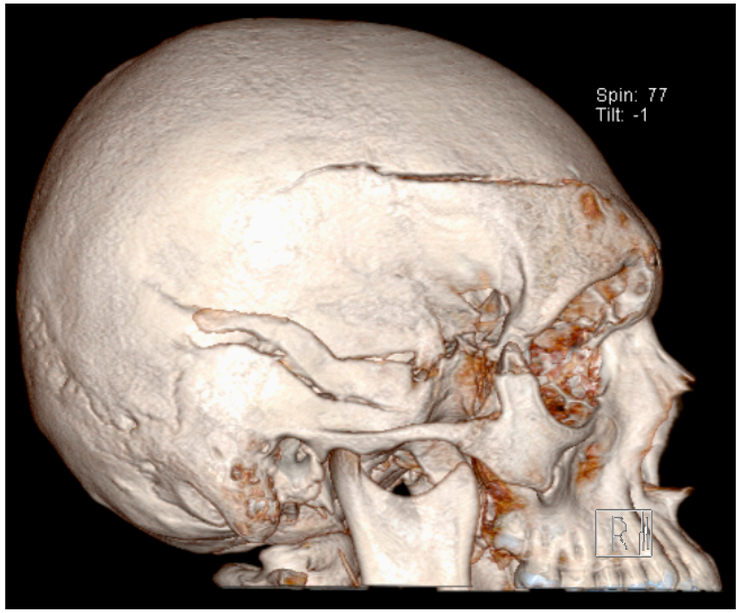
Case 2

- 13 year old male involved in rollover MVC at high speed where he was unrestrained, pinned and extricated by EMS.
- GCS 5 = E1 V1 M3 on arrival and intubated immediately. Right pupil 6 mm and non-reactive, left pupil 3 mm - reactive









Traumatic Brain Injury (TBI): Moderate/Severe

ALGORITHM 1: Post-Resuscitation

Glasgow Coma Scale (GCS) 9-12 Post resuscitation
(Consider for children under 2 years old with concern for acute abusive head trauma)

Glasgow Coma Scale (GCS) less than or equal to 8 Post-resuscitation

Inclusion Criteria:
Patient with traumatic brain injury and Glasgow Coma Scale (GCS) less than or equal to 12

Exclusion Criteria:
Patients found down without clear traumatic brain injury (TBI)

(Can be used in conjunction with Post Cardiac Arrest Pathway if considered beneficial)

Emergency Department Management
Trauma and Neurosurgery Consult
Head Computed Tomography (CT) scan- if not already obtained (STAT upload) or a quick MRI as a viable (radiation-free) option
2 IVs with Normal Saline (NS) as maintenance
Modified Rapid sequence intubation (RSI) if not already performed

For patients with signs of elevated intracranial pressure (ICP) empirically treat
- 3% (0.5 mEq/mL Na+) Hypertonic saline (HTS) bolus 5mL/kg/dose via peripheral IV or central line
- For patients with ongoing seizures use the status epilepticus clinical pathway (below).
- For patients with severe TBI who have not received a dose of levetiracetam at another institution, give levetiracetam 20mg/kg IV (max 2 grams)
- If transporting to Operating Room: Consider mild hyperventilation to PCO_2 of 32-35 mmHg

Monitor GCS. GCS decrease to less than or equal to 8? — Yes

No

- Consider comfort sedation and standard neuroprotective measures.
- Complete frequent neurologic exams.

Surgery Indicated? — No / Yes

Operating Room

Surgery as indicated

PICU

Improving or stable? — No / Yes

- Standard Neuroprotective measures**
- Standard neuroprotective monitoring ***
- Anschutz: Neurocritical Care (NCC) Consult OR Colorado Springs: Neurology Consult

If external ventricular drain (EVD)/intracranial pressure (ICP) monitor placed per neurosurgery, follow **Intracranial pressure (ICP) management algorithm (Next page)**

Continue clinical monitoring and consult Physical Medicine & Rehabilitation (PM&R)

***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

****Standard Neuroprotective Measures:**
- Head of bed at 30°, midline
- Non-restrictive cervical-collar
- Sodium greater than 140 mmol/L
- Normothermia 36.8 °C
- Oxygen Saturation 93%-97%
- PCO_2 35-40 mmHg
- Normoglycemia 80-180 mg/dL
- Levetiracetam 10mg/kg/dose BID x 7 days (Max dose 1,000mg BID)
- Appropriate sedation

Rehab Considerations for Severe TBI Patients
- Consult Physical Medicine & Rehabilitation (PM&R) for patients that have stabilized or have been hospitalized greater than 5 days
- Consult PT/OT within 48 hours of 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
- Anschutz: Consult rehab neuropsychology when PM&R is consulted

Algorithm 2. Moderate/Severe Traumatic Brain Injury (TBI) Intercranial 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	MAP (mmHg)	ICP (mmHg)	CPP (mmHg)
0-2	50-70	<15	35-55
2-5	60-80	<20	40-60
6-8	65-85	<20	45-65
9 +	70-95	<20	50-75

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

Standard Neuroprotective Measures:
- Head of bed at 30°, midline
- Non-restrictive cervical-collar
- sodium greater than 140 mmol/L
- Normothermia 36.8 °C
- 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
- 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

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:

Intracranial pressure (ICP) monitor placed at the discretion of neurosurgery

Inclusion Criteria:
Patients with Moderate/severe TBI with an ICP monitor in place

Exclusion Criteria:
Patient without an ICP monitor in place

Sedate for comfort. Responsive to touch or name. See sedation section for guidance.

Neuroprotective monitoring including ICP

Elevated ICP? — No / Yes

Elevated intracranial pressure (ICP) Parameters

For patients that are calm, unstimulated and outside of cares:
- Actively treat for an ICP of greater than 20-25 mmHg for more than 10 minutes

For a patient that is in pain, agitated or receiving cares:
- Ensure appropriate sedation/ analgesia
- Consider treating ICP greater then 30 mmHg for longer than 10 minutes after appropriate sedation or the end of cares

When treating, treat to a goal ICP of less than 20 mmHg

External ventricular drain (EVD) in place? — Yes / No

ICP less than 20 — Ensure appropriate cerebral spinal fluid (CSF) drainage. See CSF Drainage box.

ICP greater than 20 — **Hyperosmolar Therapy**
Bolus hypertonic saline (HTS) if sodium less than 165 mmol/L
If fluid overloaded or not responsive to HTS, bolus mannitol 0.5-1g/kg/dose if osmolarity (Osm) less than 340 MOSM/Kg. Can Repeat after 15 minutes if ICP is elevated

Elevated ICP? — Yes / No

Start ***deep sedation*** with goal State Behavioral Scale (SBS) equal to -3

Elevated ICP? — Yes / No

Continue current ICP directed Therapies 24 hours. Then wean per pathway.

Notify neurosurgery (NSYG), trauma and Neurology critical care (NCC)
Neuromuscular Blockade
Consider Repeat CT Scan

Elevated ICP? — Yes / No

Maximized External ventricular drain (EVD) drainage and hyperosmolar therapy? — No / Yes

Maximize external ventricular drain (EVD) drainage and Hyperosmolar therapy. Discuss with Neurology if EEG remains reactive, if so could consider further sedation.

Once neuromuscular blockade has started, maintain sedatives and analgesics at current rate.

If greater than 3 PRN doses in 1 hour call PICU provider to discuss.

Continue sedation for ICP management if effective.

Consider Salvage Therapies via PICU and Neurosurgery attending to attending call:
- Decompressive Craniectomy
- Hypothermia to 32-34°C
- Barbiturate Coma

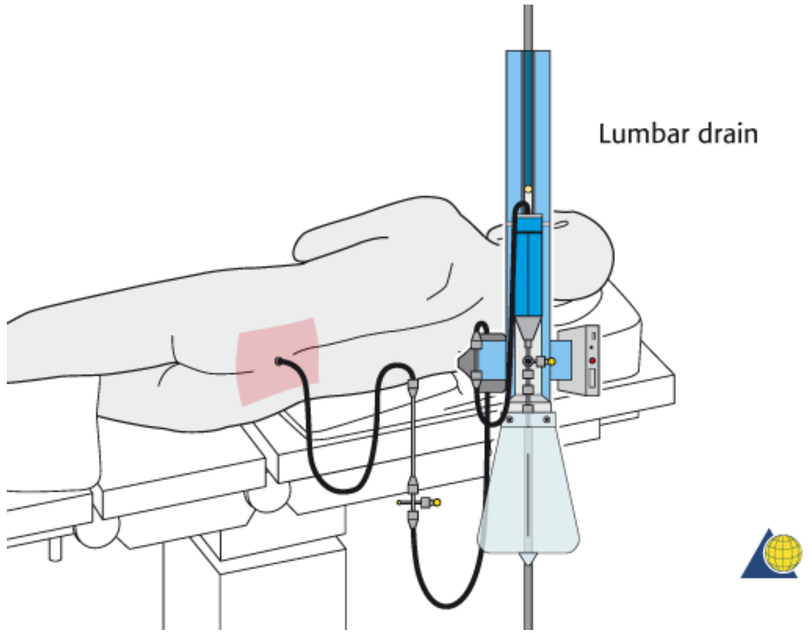
Pupillometry

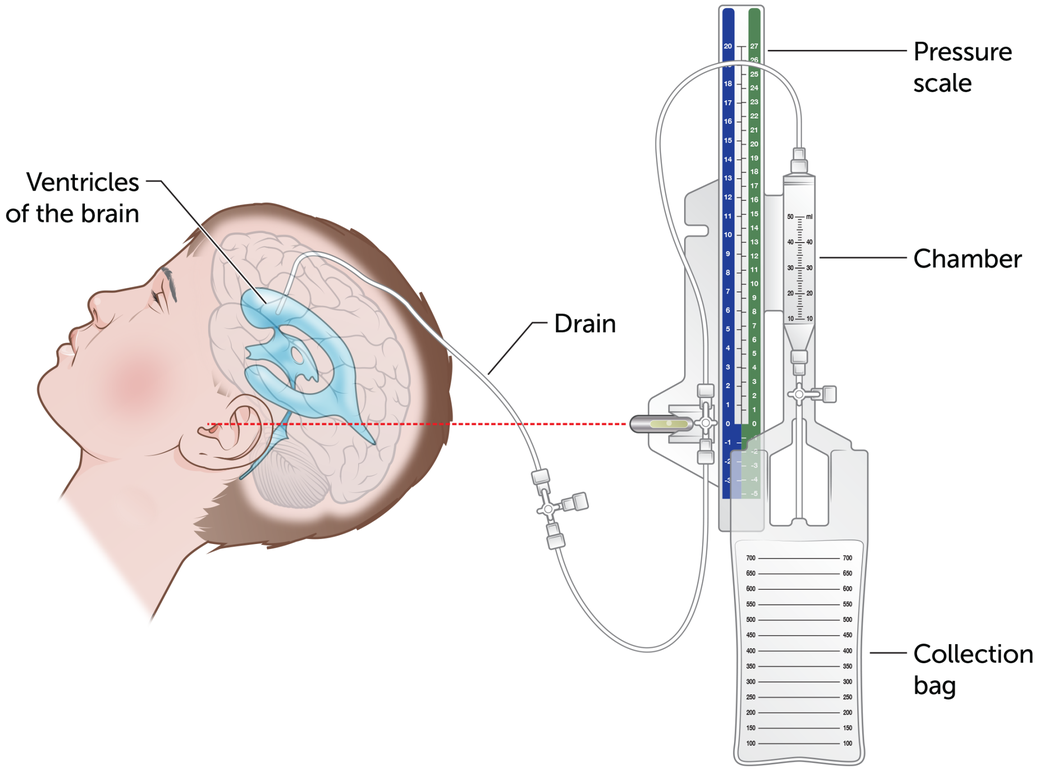
- **Measurement of fluctuations in pupillary size in response to a light stimulus**
- **Automated tool to improve clinical accuracy and detect smaller changes that may lead to sooner interventions***
- **Neurological Pupil Index or NPi = 0 - 4.9 -> algorithm with size, latency, constriction velocity, dilation velocity compared to normative data**
- **Normal pupillary responses > 3.0**
- **Abnormal < 3.0**
- **More than 70 published articles in academic, peer reviewed journals**

*Aoun, Salah G.; Stutzman, Sonja E.; Vo, Phuong-Uyen N.; El Ahmadieh, Tarek Y.; Osman, Mohamed; Neeley, Om; Plitt, Aaron; Caruso, James P.; Aiyagari, Venkatesh; Atem, Folefac; Welch, Babu G.; White, Jonathan A.; Batjer, H. Hunt; Olson, Daiwai M. (2020). "Detection of delayed cerebral ischemia using objective pupillometry in patients with aneurysmal subarachnoid hemorrhage". *Journal of Neurosurgery*. **132** (1): 27–32. doi:10.3171/2018.9.JNS181928. PMID 30641848. S2CID 58575267.

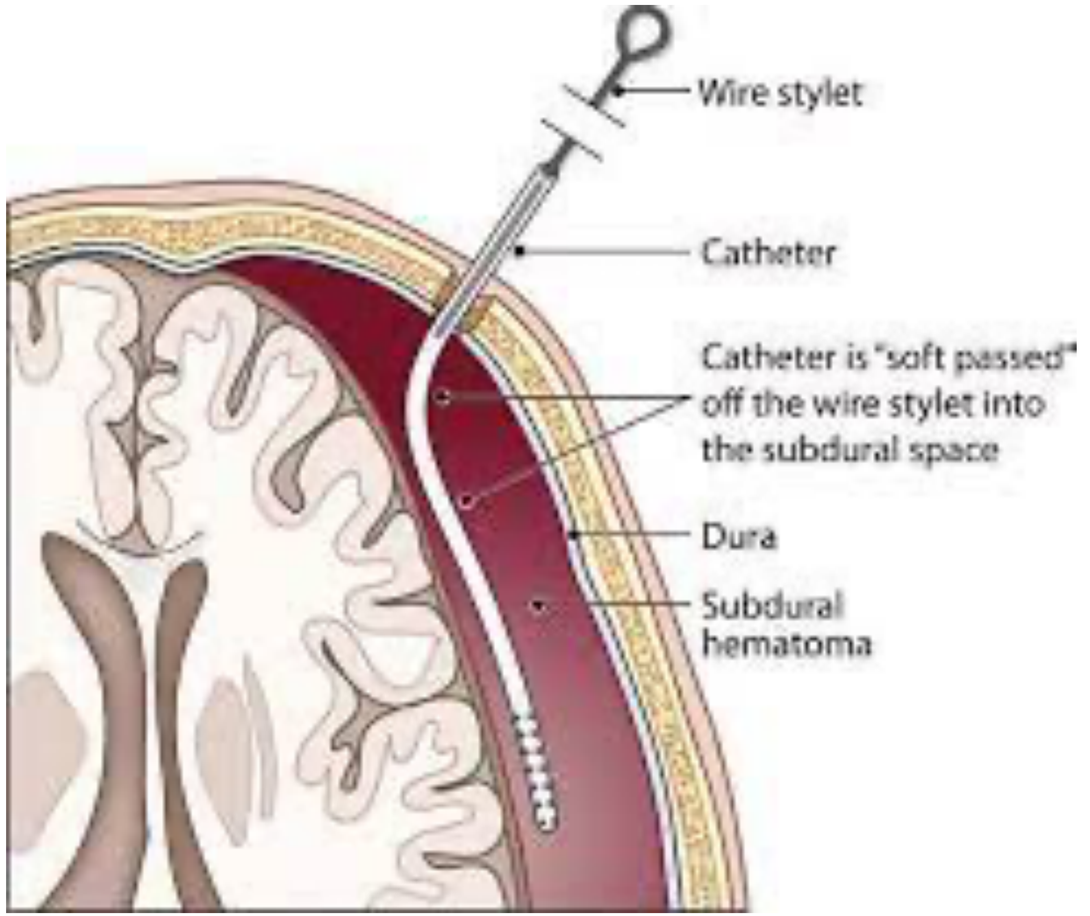
Case 3

- 4 month old infant with progressively worsening irritability, increasing head circumference, and looking down more.





Subdural drain placement and then eventual placement of subdural peritoneal shunt



Questions ?