TCD IN THE NICU, PICU AND OTHER APPLICATIONS

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Objectives

- Recognize normal and abnormal cranial blood flow patterns
- Identify applications for TCD in the critical ill child
Transcranial Doppler (TCD)

Alterations in blood flow following
- asphyxia
- trauma
- subarachnoid hemorrhage

Clinical indications include
- Vasospasm - Hydrocephalus
- ICP - Vasculitis
- Sickle Cell - Brain death
Factors impacting intracranial flow:

- Arterial narrowing: Vasospasm, stenosis
- Occlusion: proximal, local
- Head injury
- Changes in CO$_2$: sleeping, crying
- Age: flow velocity decreases with age
Protocols and Technique are Specific to Type of Examination:

- What is the clinical question?
- What are the presenting symptoms?
- Do other vascular studies provide info?
- Baseline exam for reference?
- Bedside, OR, ICU, ER or vascular lab?
- Which instrument provides the best data for this exam?
- Experienced examiner?
Neonatal Technique - Open Fontanelle
Neonatal technique

- Open Fontanelle
Vein of Galen Aneurysm
Feeding vessels, nidus and draining veins
Normal venous sinuses
Beware!
Dural sinus fistula
Subdural hematoma

Nonaccidental trauma - no crossing vessels, compressed, flat gyri.
Transcranial Doppler Technique
Neonate - Anterior Fontanelle

Ant Cerebral Artery
- Sagittal midline

PSV 26.7 cm/s
EDV 7.18 cm/s
RI 0.73
8.1
Transcranial Doppler Technique
Neonate - Anterior Fontanelle

Middle Cerebral Artery
right and left via coronal plane
Left MCA stroke
Resistive Index

Peak Systole – End Diastole

Peak Systole

- Minimize affect of angulation

Age dependent values

- Preterm infant 0.77 ± 7%
- Term infant 0.7 ± 7%
- By age 2 0.5 ± 15%
Resistive Index

- An **increase** in diastolic flow will result in a decrease in RI

- A **decrease** in diastolic flow will result in an increase in RI

- as ICP increases above mean arterial pressure, diastolic flow may become **reversed** RI > 1.0.
Hydrocephalus

- RI useful to identify increased ICP
Hydrocephalus

Goh et al - RI sign of ICP
  - >0.8 in neonate
  - 0.65 in children

Use to determine who needs to be tapped or shunted
Hydrocephalus

- Post tap, RI will decrease
- Persistently elevated RI may imply need to shunt
Determine Change in RI

Compression for 3-5 sec

Degree of compression until no change in RI
Beware!

Head connected to the body!!
Patent Ductus Arteriosus
Hydrocephalus in Adults

- Resistive Index - wide variation of normal
  - overlap nl/abn
- Need baseline values
- Need close correlation with clinical findings
Shunt Failure
Asphyxia

- May result in **impaired cerebral autoregulation** producing an increase in diastolic blood flow.
- Term infants following asphyxia.
  - Low RI (< .6) within the 48º of asphyxia correlated with poor neurologic outcome.

*Archer et al, Siebert et al*
Hypoxic Ischemic Encephalopathy?

RI = .46
Asphyxia

- Loss of autoregulation described in older child after head injury or cardiac arrest.
  
  Bode et al

- May be useful in predicting cerebral injury

- If hyperventilation fails to alter the waveform pattern - vasomotor paralysis.
Hyperventilation

- $\text{CO}_2$ vasodilates $\rightarrow$ diastolic flow $\rightarrow$ RI.

- Low $\text{pCO}_2$ vasoconstricts $\rightarrow$ diastolic flow $\rightarrow$ RI.

- $\text{CO}_2$ reactivity measurable

- If RI doesn’t change with hyperventilation, severe brain injury present
Ruptured Intracranial Aneurysm

- 50% die within minutes
- ACA, ICA & MCA most frequent sites
Vasospasm

- Develops in first 2 days after SAH.
- Peaks 2 weeks later.
- Declines gradually during the subsequent 3 weeks.
Vasospasm

- As cross sectional area of vessel decreases, blood velocity increases
- TCD highly specific
  - Increased flow velocities precede clinical sx of cerebral ischemia
- Guide optimal timing of surgery and Rx
- Decrease velocity > appropriate time to stop Rx
- Minimize complications, shorten ICU stay
Hemodynamics of Vasospasm:

- Attempt to maintain flow volume
- Elevated velocity often precedes onset of neurologic symptoms
- Velocity data impacts management
Vasospasm Protocol and Criteria:

Criteria:

- **Reach maximum**: 7-12 days; resolve 3 wks.
- **Mild**: PSV 100-120 cm/sec
- **Moderate**: 120-200 cm/sec
- **Severe**: >200 cm/sec
  - risk for ischemia
- **Rapid increase**: PSV >25-50 cm/sec/day
  - poor outcome

Exam Protocol:

- Perform complete baseline study: R & L
- Identify highest velocities
- Monitor daily
Vasospasm

18 yo s/p SAH LMCA >250 cm/s

Therapy recommended with rapid increase vel (>50 cm/s/day) or MCA PSV > 200 cm/sec
Vasospasm

- Proximal MCA most accurate
- Severe
  - PSV > 200 cm/sec
  - rapid increase (>50 cm/s/day)
  - Mean CBFV MCA/ICA ratio (cm/s)
  - Lindegaard Ratio
    - < 3 Nonspecific
    - 3-6 Mild
    - 3-6 Moderate
    - >6 Severe

Errors:
- increased ICP
- low volume flow
- peripheral vasospasm

Combine with CLINICAL and LAB DATA
Cerebral vasculitis

- Small vessel vasculopathy
- Rare in children
- Acute stroke
- Causes - post infectious, autoimmune, idiopathic.

PSV 310 cm/sec  LMCA.
Traumatic Brain Injury

- Pathologic processes often result in significant changes in cerebral hemodynamics.

- Timely dx crucial in head injury management.
Traumatic Brain Injury

Acutely

- Loss of autoregulation - decrease in RI
- Vasospasm from SAH or posttraumatic hypervolemic - CBF velocity may increase
Traumatic Brain Injury

If cerebral edema develops, RI will increase

- Vessels vasoconstrict
- As ICP increases above mean AA pressure, diastolic flow reverses. (RI>1)

\[ RI = 1.4 \]
Decrease then reversed diastolic flow
Progression to Brain Death

- **Arrest of CBF** at microcirculation level.
- Large vessels distend/constrict, thrombose/collapse.

- **Cerebral circulation arrest**
  - Decrease in systolic velocity.
  - Small spikes
Following trauma, Flow patterns - 4 categories

1. No significant intracranial flow
2. Reversal of diastolic flow
3. RI elevated
4. RI within normal range
1. No significant flow
2. Reversal of diastolic flow

- Typically clinical criteria for brain death within 24 hours of this pattern
3. Elevated RI with antegrade diastolic flow

- Can survive but may be neurologically devastated
4. Normal RI

- Typically survive but can have neurologic deficits
Retinal Artery

Reduction in Retinal Arterial and Venous flow velocities in children w/ elevated ICP

Miller et al J of Child Neurology 2009;24:30
Miller et al. J of Child Neurology 2009;24:30
Retinal Artery

Another potential adjunct to monitor ICP

- in the acute setting
- when serial evaluations are needed
- if transtemporal TCD or ICP monitoring not available
Safety

- Can cause heat and cavitation
- Must keep output to a minimum
- ALARA
- Limit examination time
Traumatic Brain Injury

- Serial TCD readings can evaluate progression of cerebral edema
  - follow course of treatment.

- Useful to assess response to hyperventilation
Decreasing CO$_2$ - cerebral vessels vasoconstrict

- RI should increase

- Children w/ reduced or absent PaCo$_2$ vasoreactivity w/in 24°of injury
  = **vegetative or died**

Beyda DH,. Wade ed. 1987
Establishing brain death can be problematic.

- Neurologic examination-apnea test
- EEG
- Brainstem evoked potential
- Nuclear blood flow studies

*The use of TCD adds another noninvasive method of determining brain death*
Brain Death-TCD Advantages

- Noninvasive
- Repeatable
- Portable
- Inexpensive
- Ease in performing
- **Can be used in phenobarb coma**
  - (EEG nondiagnostic).
Brain Death?
Brain Death?

Day 3

Day 5
Cerebral Angiogram
Brain Death

Reversal of diastolic flow can be characteristic of essentially **absent effective cerebral circulation** in the adult and older child.
Direction of Flow Index

- Kirkham - Direction of Flow Index:
  \[
  \text{DFI} = 1 - \frac{\text{peak systolic velocity area}}{\text{peak diastolic velocity area}}
  \]
  
  If DFI negative - area of reverse flow > forward flow

- All children with a negative DFI and time ave velocity < 10 cm/sec over 30 min died w/out brainstem function recovery.
  
Brain Death Patterns

- Small early systolic spikes
Brain Death Patterns
Brain Death Patterns

- Absent flow in MCA
- Reversal of diastolic flow in extracranial ICA
Infant Brain Death

Concern of TCD reliability in infant brain death assessment

- In neonates, low RI’s have been described in clinically dead patients.
- Infants with extremely high RI’s have survived

Careful clinical correlation crucial in determining brain death as arrest of supratentorial flow not synonymous with brain death rather it is confirmatory
Brain Death

- **TCD exam** should never be used in isolation to supplant clinical neurologic findings in children and neonates.
- Provides data indicating severity of cerebrovascular arrest.
- Repeat study to confirm CBF arrest sufficient to cause irreversible damage to supratentorial structures.
Conclusions

**TCD** can be used to monitor children with severe head injury

- portable
- noninvasive
- rapid
- can be repeated often

Provides a useful adjunct in the clinical assessment of the injured patient.
US is a powerful tool

Provides a useful adjunct in the neurologic assessment of the critically ill patient.
Thank you!
Retinoschisis
Optic Nerve Sheath

- Optic NN surrounded by CSF and dura forming the *optic nerve sheath (ONS)*

- Connected to the subarachnoid space, ONS diameter is influenced by CSF pressure variation
Optic Nerve Sheath Diameter

- Rapid diagnosis of Intracranial Hypertension can be critical to appropriate therapy
- Invasive procedures such as ICP monitoring or neuroimaging may not be available
  - CT may underestimate the amount of ICP elevation
Optic Nerve Sheath Diameter

- Several ONSD Studies have demonstrated correlation with direct measurement of ICP
  - low interobserver variability

*Meretti et al* Acta Anesth Scan 2011
Technique

- High frequency linear probe > 7.5 MHz.
- Gel on closed eyelid - No pressure
- “Superficial” program
  - 4-5 cm depth
  - gain optimize contrast b/w ONS and periorbital fat.
- 2 measures in transverse and sag planes - mean
Optic Nerve
Measured 3 mm behind the
ONSD Measurement cut offs

- > 4 yo to Adults – 5mm
- 1-4 years – 4.5 mm
- < 1 yo – 4 mm

- Bedside US of ONSD may be useful in assessing ICP if invasive monitoring not feasible
ONSD Problems

- No clear consensus on upper normal ONSD limit
- Difficulty measuring diameter
  - dependent on experience, frequency of probe, age of equipment.
- Rapid ICP changes may underestimate measures- lag times documented