Going Beyond the Gold Standard:
Integrating new neuromonitoring technologies to improve patient care

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Disclosure
- No financial relationships to disclose
- This session provides a broad overview of available technology
- Any reference to a specific brand or product is not intended as an endorsement, but rather a reflection of the device or product in which we are familiar.

Objectives
- Identify limitations of traditional neuromonitoring devices
- Describe emerging neuromonitoring technologies
- Discuss the integration of traditional and newer neuromonitoring data on patient outcomes.

Historical
Trepanning; from Greek τρυπάνων, ‘borer’
- Oldest surgical procedure
- Transcultural
- Transcontinental
- Evidence of survivability, multiple procedures on single human

Primary Injury
- Damage that is complete at time of impact

Secondary Injury
- Damage that continues to evolve after initial insult
Secondary Injury

- INFLAMMATION
  * ICP
  * Edema

- ISCHEMIA
  * Hypotension
  * HCT

- HYPOXIA

- INFECTION

- METABOLIC
  * Hypercapnia
  * Acidosis
  * Release of Neurotransmitters

Penumbra

- Area of Infarct
- Area of injured / at risk tissue

Computed Tomography

- First 'look'
- Midline shift
- Mass or lesion
- Infarct (time limiting)
- Hemorrhage
- Ventricle size
- Grey/white differentiation

ONLY a SNAPSHOT!

***normal CT scan cannot exclude the presence of an elevated ICP as there is a high probability of false-negative results

Magnetic Resonance Imaging

- Uses magnetic fields and radio waves
  - More soft tissue detail
  - Contrast less nephrotoxic
  - Incompatibility issues

Monroe Kellie Doctrine

For any increase in volume in one compartment of the cranial contents, there must be a compensation in another

Intraventricular ICP monitoring

- Developed by Dr. Lundberg 1960's

Advantages
  - CSF drainage
  - Waveform analysis
  - Can re-zero
  - Place @ bedside or OR
  - Inexpensive

Disadvantages
  - Global pressure
  - Accessing ventricle
  - Clotting
Intraparanchymal ICP monitoring

Pressure is transduced through or fiberoptic fibers or microchip

Advantages
• Useful when ventricle not accessible

Disadvantages
• Cannot drain CSF
• Measures localized pressure
• Drift; Cannot be recalibrated in Vivo

Normal Values

<table>
<thead>
<tr>
<th></th>
<th>MAP</th>
<th>ICP</th>
<th>CPP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>•70 – 110 mmHg</td>
<td>•5 – 15 mmHg</td>
<td>•60- 90 mmHg</td>
</tr>
</tbody>
</table>

ICP and CPP Limitations

Global vs localized ICP

Optimal CPP
• Intact autoregulation
• Injured brain

Loss of the “Box”

ICP/CPP
• reference
• specificity

Pupilometry

Cranial Nerve III

Pupil reaction correlates with brainstem oxygenation and perfusion

Parasympathetic
*constriction

Sympathetic
*dilatation

Pupilometer

Digital Video of pupil response to light

• 30 pictures per second
• Multiple measurements
**Pupilometer**

Measures
- Baseline size (max)
- Constriction size (min)
- Percent change of pupil size
- Latency
- Constriction velocity
- Dilatation velocity

**NPi™**
- Scale 0-5
- Score <3 indicates sluggish pupil and abnormal pupillary response

**NPi™ and ICP**

**Pupil Size vs. Function**

**Advantages**
- Noninvasive, portable
- QUANTITATIVE
- Good on dark irises, pinpoint pupils
- Most ICU meds do not affect light reactivity
- RN performs

**Disadvantages**
- Cost of device
- Maintaining headsets
- Hand enter to EMR
**Variable Reported by Pupilometer**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit of Measure</th>
<th>Definition/Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pupil Max/Min Size</td>
<td>mm</td>
<td>Minimum pupil size is the pupil size at the peak of the constriction. Maximum pupil size is the initial resting pupil size and is defined by the mean pupil size during the latent period.</td>
</tr>
<tr>
<td>Constriction % or Percentage Change</td>
<td>%</td>
<td>Constriction percentage is defined as maximum size minus minimum size divided by the maximum size.</td>
</tr>
<tr>
<td>Latency</td>
<td>seconds</td>
<td>Time difference between the initiation of retinal light stimulation and the onset of pupillary constriction.</td>
</tr>
<tr>
<td>Constriction Velocity</td>
<td>mm/sec</td>
<td>Amount of the constriction divided by the duration of the constriction; this results in a average velocity.</td>
</tr>
<tr>
<td>Maximum Constriction Velocity</td>
<td>mm/sec</td>
<td>Peak value of the velocity during constriction; this is larger than the previous average velocity.</td>
</tr>
<tr>
<td>Dilation Velocity</td>
<td>mm/sec</td>
<td>Amount of pupil size recovery (after the constriction) divided by the duration of the recovery.</td>
</tr>
<tr>
<td>NPI (Neurological Pupil index)</td>
<td>Scalar value</td>
<td>Algorithm that takes all variables above as inputs and compares to normative model to give a composite score of pupillary response.</td>
</tr>
</tbody>
</table>

**Optic Nerve Anatomy**

- Potential space
- Size increases with edema

**Optic Nerve Ultrasound**

- Measures Optic nerve sheath (ONS) diameter
- ONS diameter > 0.5 cm correlates to an ICP > 20
- 95% specificity
  - (Rajajee, Neurocrit Care 2011)

**Advantages**
- Noninvasive
- Existing equipment
- Low operator variability

**Disadvantages**
- No optic nerve injury
- Cannot predict specific ICP value above 20

**Near Infrared Spectroscopy (NIRS)**

- Uses near infrared light technology
- Reflects the balance of oxygen delivery to oxygen consumption in a regional capillary tissue bed

**Regional Saturation of Oxygen (rSO2)**

- Normal: rSO2 60-80
- Intervention Trigger:
  - <50 or >21% from baseline
- Critical Threshold:
  - <45 or >25% from baseline

- Capillary tissue bed
  - Arterial (75%)
  - Venous (25%)

- Increases with a rise in delivery or a fall in demand
- Decreases with a fall in delivery or an uncompensated rise in demand
Supply and Demand Balance

Cardiac Output
CPP
FiO2
HCT
R/O mechanical obstruction

NIRS
Advantages
- Noninvasive
- Continuous reading
- Requires caregiver interpretation
Disadvantages
- Site specific
- Limited depth
- Chromophore influenced
- Requires caregiver interpretation

Transcranial Doppler
Measures velocity of flow in cerebral vasculature
Increased velocity = vasospasm

Advantages
- Noninvasive
- Detection of vasospasm
- Detection of microemboli

Disadvantages
- Snapshot only
- Inaccuracy due to loss/poor windows
- Special training

Continuous EEG
Measures voltage fluctuations resulting from ionic current flows within the neurons of the brain
- Detect subclinical seizures
- Can precede ICP increases
- Identification of further deterioration

Advantages
- Realtime continuous read
- Non invasive
- Treatment of subclinical pathology
- Indications in post cardiac arrest

Disadvantages
- RN training
- CT/MRI compatibility
- Cost
Physical Exam
What it tells you about the “black box”

Advantages
• Free
• Performed anywhere
• Validator for monitoring data

Disadvantages
• Operator experience
• Consistency

Cerebral Oxygen
Must be a constant supply

Delivery  O2 Content  Affinity

Venous Jugular Bulb

Fiber-optic catheter, placed retrograde in one of the internal jugular (IJ) veins
Reflection of global cerebral oxygen
Rarely used anymore

Intraparanchymal Cerebral Oxygen Monitor

Intraparanchymal catheter measures interstitial brain tissue oxygenation

Licox

• Measures partial pressure
• Assumes PbtO2 is a marker for adequate CBF
• Individualize CPP goal

Licox Values

<table>
<thead>
<tr>
<th>PbtO2 Value</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-50 mmHg</td>
<td>Adequate oxygenation</td>
</tr>
<tr>
<td>&lt;20 mmHg</td>
<td>Cerebral hypoxia</td>
</tr>
<tr>
<td>&lt;10 mmHg</td>
<td>Severe cerebral ischemia</td>
</tr>
</tbody>
</table>
PbtO2 < 20

- ICP > 20 mmHg
  - Reduce ICP
  - Increase CPP
  - Check Airway
  - Increase FiO2

- ICP < 20 mmHg
  - Optimize CO
  - Check Airway
  - Adjust ventilator
  - Ventilation
  - Oxygenation
  - Euvolemia
  - Consider transfusion

PbtO2 Demand

- Normothermia
- Sedation/Analgesia
- Environmental Stimulus
- Shivering?
- Seizure?

Cerebral Perfusion

Different for intact vs. nonintact autoregulation

Each person’s ‘sweet spot’ is different

Make assumptions that 60 is a magic #

Cerebral Blood Flow Monitor

Measures actual cerebral blood flow (CBF) in ml/100 g/min

Uses thermal conductivity

Diminished Flow Vasospasm Tissue water content

Cerebral Vascular Resistance (CVR)

Cerebral Vascular Resistance

\[ \text{CBF} = \frac{\text{CPP}}{\text{CVR}} \]

Probe

Three phases of Measurement

- Temperature Stabilization
- Calibration
- Perfusion Measurement

Takes approx. 7 minutes

Cool down is flow dependent

Long cool down = Low Flow
**Hemedex Measurements**

- CBF = 20-35 ml/100g/min
- K = 4.8 - 5.9
- ΔT = 2.5 - 3.5
- PPA = < 4.9

**Cerebral Blood Flow Monitoring**

**Advantages**
- Realtime, continuous monitoring
- Placed @ bedside
- Brain temp
- Early detection/interventions

**Disadvantages**
- Location specific
- Sensitive to nearby chatter
- Unable to use when brain temp>39.5
- Not MRI compatible

**Driving Practice**

- CBF = 20-35 ml/100g/min
- K = 4.8 - 5.9
- ΔT = 2.5 - 3.5
- PPA = < 4.9

**Cerebral Microdialysis**

- Measures local tissue chemistry of brain
- FDA approved for bedside use in 2005
- Indicates impact of tissue injury

**Anaerobic Metabolism**

- Glucose
- L/P ratio
Cerebral Microdialysis

- Lactate ↑
- Pyruvate ↓
- Glucose ↓
- Glutamate ↑
- Glycerol ↑

Glycerol
Reflects cell injury/lysis
Normal: 20-50 uM

Glutamate
Reflects cell membrane breakdown
Normal: 10 uM

Lactate
Reflects cell metabolism
Normal: 2.9 ± 0.9 mM

Pyruvate
Reflects cell metabolism
Normal: 166 ± 47 uM

L/P Ratio
Reflects anaerobic metabolism
Normal: 23 ± 4

Glucose
Reflects available energy
Systemic Glucose
Approx. 2/3 systemic glucose
Normal: 1.7 ± 0.9 mM

Edema
- 3%
- Fever control
- Stimulation
- Head position

Available energy
- Glucose
- CBF
- O2

Catheter
- Semi-permeable membrane
- Collection microdial
- Placed in pericranium
- May place 2nd in ‘good’ brain

Pump
- Circulates artificial CSF through catheter
- Pumps ⊓ 0.3 μL/min
- Battery operated

Analyzer
- POC chemistry analyzer
- Can run up to 9 catheters at once
- ESR download
Driving Practice

Changes in LP ratio following depressive craniectomy

LP ratio changes in both 'good' and bad brain

Driving Practice

Changes in LP ratio during vasospasm

Changes in LP ratio in tight vs. loose glycemic control

Cerebral Microdialysis

Advantages
- Early warning
- Evaluate interventions
- Trigger for further intervention
- Performed at bedside

Disadvantages
- Location sensitive
- POC Regulations
- No continuous read
- RN training

Current Controversies in Neuromonitoring
**BEST TRIP Trial**  
*Benchmark Evidence from South American Trials: Treatment of Intracranial Pressure*
- Multi-center study
- 324 pts; age 13 and older
- Treatment based on ICP monitoring vs. Exam/Imaging

✓ No statistical difference between survival or functional outcome  
✓ Shorter ICU stay, less interventions in ICP group

“Although it questions how we currently interpret the ICP values, it does not question their importance. For all centers, it solidly supports that sTBI patients require aggressive treatment of intracranial pressure by whatever means is available” - Dr. Randy Chestnut

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**TRACK- TBI Study**  
*Transforming Research and Clinical Knowledge in Traumatic Brain Injury*
- Multi center study @ 3 Level 1 facilities
- 135 pts. w/ mild TBI
- CT scan on admission
- MRI about 1 week later

✓ 99 had no detectable signs of injury on a CT scan  
✓ More than a quarter (27) who had a “normal” CT scans had focal lesions on MRI

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**CT Radiation**
- Brigham and Women’s Hospital
- 31, 462 pts
- Retrospective 22 yr CT exposure history

✓ 33% of patients underwent five or more lifetime CT examinations  
✓ 5% of patients had received estimated cumulative radiation doses that were higher than the radiation exposure from 1,000 chest X-rays.  
✓ 7% of the patients had enough recurrent CT imaging to raise their estimated cancer risk

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**BOOST 2 Trial**
- Phase 2 randomized clinical trial
- Median time when PbtO2 < 20mmHg
  - 0.44 in the ICP group
  - 0.14 in the ICP+PbtO2 group (p<0.00001)

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**NCS/SCCM Consensus Statement**
- Use of ICP and CPP protocol  
- Monitoring brain temp.  
- Monitoring brain oxygen for all pts at risk for cerebral ischemia  
- Use of TCD to detect vasospasm in SAH

- Use of EEG  
  - Hypothermia  
- Use of cerebral microdialysis

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**Putting Neuromonitoring Devices into Practice**
Jimmy
14 year old wearing helmet
Unwitnessed bicycle crash on dirt trail
GCS on scene 6; intubated in field
Airlift to hospital
** Report of Concussion 6 Weeks PTA**

Initial Scan and Physical Assessment

- Left basal ganglia hemorrhage
- Small Right frontal contusion
- Small SAH
- Nondisplaced left mandibular fracture

Initial Interventions

- Foley placed
- A line placed
- Versed and Fentanyl Gtt
- Right Frontal Camino
- Opening ICP 19

Physical Exam

- Sedated
- Fixed Dilated Right pupil
- Moves hand slightly to noxious stimuli
- Temp 39.1, BP 126/61, HR 76

TBI Goals
2007 Brain Trauma Foundation

- CPP >50 mmHg
- Titrate MAP for CPP goal
- ICP <20 mmHg
- Normothermic*
- PaO2 >75
- Euvolemic
- Na+ 140-150 mmEq/L

Hospital Day 3

- Increasing ICP 24-28 mmHg
- Left Temporal Craniectomy; flap out
- Placement of Neuromonitoring devices:
  - Microdialysis x 2; left parietal, left frontal
  - Hemedex
  - Licox
  - Ventriculostomy
Day 4: 0800-1100

- BP 118-122/48-52 mmHg
- MAP 64-70 mmHg
- ICP 9-10 mmHg
- CPP 54-61 mmHg
- CBF 21-26 ml/min
- PbtO2 8.5-9.8 mmHg
- L/P ratio 26-28
- Cerebral CBG 0.9-1 mmol/L

Midazolam gtt
Fentanyl gtt
Phenytoine gtt

Day 4 @ 1140
Fentanyl Bolus IV given for anticipated placement of weighted feeding tube

Day 4 @ 1200
- BP 95-98/35-40
- MAP 55-60
- ICP 7-9
- CPP 49-53
- Hemedex 9-10 ml/min
- Licox 8 mmHg
- L/P 32

No alarms are generated; Is there a problem?

Day 4 @ 1400
- BP 118-122/50-33 mmHg
- MAP 65-70 mmHg
- ICP 9-10 mmHg
- CPP 55-65 mmHg
- CBF 21 ml/min
- PbtO2 10 mmHg
- L/P ratio 36

The Bottom Line

- No one monitor tells the whole story
- Location
- Context
- Validation
- Triggers additional assessment
- ‘Sweet Spot’ targeted care

References:
References Continued


Thank You!

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