Introduction to Neurocritical Care

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Agenda

• The background of Neurocritical Care

• Basic physiology and pathophysiology

• Therapeutic principles

• Multimodality monitoring
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Neurocritical Care is a multidisciplinary subspecialty which focuses on the management of patients who have sustained (or are at risk for) severe injury to the central or peripheral nervous system.
Origins of Neurocritical Care

World War II - Sir Hugh Cairns

- British Neurosurgeon
- Disciple of Harvey Cushing
- Established mobile head injury units for the army
- Neurologist, Neurosurgeon, Anesthesiologist

1896 - 1952
Origins of Neurocritical Care

Polio Epidemic - peak in the 1940’s - 1950’s
Origins of Neurocritical Care
Iron Lung Units - Managed by Neurologists
Origins of Neurocritical Care
Origins of Neurocritical Care

• General intensive care units arose, few neurologists remained involved

• 1969 - dedicated NeuroICU established at University of Colorado (Michael P. Earnest)

• 1970’s - David Jackson (Neurologist, Case Western) ran a critical care training program

• 1980’s - NeuroICUs begin to arise, AAN approved section of critical care and emergency neurology
Origins of Neurocritical Care

• 1990’s - Society for Critical Care Medicine established a Neuroscience Section in recognition of the growing number of Neurointensivists

• 2002 - Neurocritical Care Society founded, first meeting in AZ (2003)

• 2007 - First Neurocritical Care Board Examination
Neuro ICU

Clinical Care
- Multidisciplinary team
- Respiratory therapy
- Pharmacy
- Nutritionists
- Advanced technology

Education
- Fellowship
- Residency
- Medical School
- CME

Research
- Basic Science
- Clinical Research
- Translational Research
- Neurologists
- Neurosurgeons
- Anesthesiologists
- Neuroradiologists
- Advance Practice RNs
Disease States

• Peri-operative neurosurgical patients
• Cerebrovascular diseases
• Head trauma
Disease States

• Peri-operative care neurosurgical patients
• Cerebrovascular diseases
  • Basilar artery occlusion
  • Carotid stenosis/occlusion
  • Occlusive vasculopathy (ie Moya Moya)
  • Massive hemispheric infarction
  • Intracerebral hemorrhage
  • Subarachnoid hemorrhage
  • Arteriovenous malformations
  • Venous sinus thrombosis
  • Carotid and vertebral dissection
  • Vasculitis
• Seizures and Epilepsy
  • Convulsive status epilepticus
  • Non-convulsive status epilepticus
  • Myoclonic status epilepticus
• Neuromuscular disorders
  • Myasthenia Gravis
  • Landry Guillain Barre Syndrome
  • Critical illness polyneuropathy
• Neurotrauma
  • Subdural hematoma
  • Epidural hematoma
  • Diffuse axonal injury
  • Skull fracture
  • Cerebral contusion
  • Penetrating injury
  • Traumatic SAH
  • Penetrating head injury
  • Spinal cord injury
  • Intracranial hypertension
• Toxic/metabolic
Tenets

• Surviving critical illness without acceptable neurological function is not “meaningful.”

• Maximizing nervous system integrity is the end point for resuscitation of patients with critical illness.
Particular Skills/Knowledge Set
You must understand:

• Relevant nervous system anatomy and physiology.
• Importance and proper use of the physical exam.
• Available tools for monitoring brain physiology and function.
• Interaction of other organ systems with the nervous system, impact of systemic insults on the nervous system.
• Available therapeutic modalities.
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Primary Injury
Secondary Injury: Organ/Systemic Level
Cellular/Molecular Level
Intracranial contents

- Brain: 1200-1500g
- CSF: 100 – 150ml (10%)
- Blood: 100 – 150ml (10%)
- Other contents: 80%
Intracranial Pressure

Monro-Kellie Hypothesis:

\[ \text{ICP} = P(\text{parenchyma}) + P(\text{CSF}) + P(\text{blood}) \]
Monro-Kellie Principle

ICP = \( P(\text{parenchyma}) \) + \( P(\text{CSF}) \) + \( P(\text{blood}) \) + \( P(\text{mass lesion}) \)
The Compliance Curve

ICP (mmHg)

$P_{eq}$

$V_{eq}$

$\Delta V$

$\Delta V$

$\Delta p$

$\Delta p'$

Volume (ml)

craniospinal compartment
The Compliance Curve

Region of high compliance - when ICP is low
The Compliance Curve

Region of low compliance - when ICP is high
ICP Monitors
<table>
<thead>
<tr>
<th>Method</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
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</table>
| EVD                 | “Gold standard”  
Therapeutic & Diagnostic  
Re-zeroing possible | Most invasive  
Risk of hemorrhage  
High infection rate  
Difficult to place in edematous brain  
No simultaneous drainage and monitoring |
| Intraparenchymal probe | Low infection rate | Measures local pressure  
Drift  
Limited accuracy |
| Subarachnoid probe  | Low infection rate  
Does not touch parenchyma | Limited accuracy  
Frequent flushing necessary |
| Epidural probe      | Low infection rate  
Easy to insert  
No dural penetration | Limited accuracy  
Relatively delicate |
| Lumbar drain        | Extradural  
Low infection rate | Inaccurate reflection of ICP  
Dangerous in face of brain edema |
Bedside Estimation of Compliance

ICP waveform analysis

$P_1$ - percussion wave
$P_2$ - tidal wave
$P_3$ - dicrotic wave
Bedside Estimation of Compliance

ICP waveform analysis
Intracranial Hypertension

• ICP 8 -12 mmHg is “normal”
• ICP > 20 associated with poor outcome after TBI
• ICP target of < 20 for TBI
• This is easy, but overly simplistic
Cerebral Perfusion Pressure

CPP = MAP - ICP

- BTF recommends CPP 50-70 mmHg
- Optimal CPP should be individually determined
- Too much pressure is also deleterious
Cerebral Blood Flow

\[ CBF = \frac{CPP \pi r^4}{8L\eta} \]

- Difficult to measure CBF in the ICU

\( r = \text{radius}, \ L = \text{length of tube and} \ \eta = \text{viscosity} \)
Cerebral Autoregulation

The brain’s ability to maintain constant blood flow across a wide range of perfusion pressures
Disturbed Autoregulation

- Disease states, e.g. trauma, may cause local or global disturbances of autoregulation

- TOP: Normal autoregulation

- BOTTOM: vasoparalysis, e.g. trauma
Disturbed Autoregulation

ICP: It's not just a number
Autoregulation Intact

- ABP increases
- Vasoconstriction should occur
- Maintaining CBF
- ICP should go down
- Pressure Reactivity Index (PRx)
- Negative correlation means intact autoregulation
ICP: It's not just a...
ICP: Its not just a number
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Management of Raised ICP
Stepwise Approach

**METABOLIC THERAPY**
- Primary reduction of CMRO2
- Secondary reduction of CBF and CBV

**CRANIECTOMY**
- Improves brain O₂ and compliance
- Effective in focal injury
- Timing and technique important

**OSMOTIC THERAPY**
- Reverse the blood brain osmotic gradient
- Draws fluid into the vascular compartment
- Increase rCBF

**SEDATION/ANALGESIA**
- Combined sedative/analgesic regimen
- Lowest necessary dose for adequate control

**UNIVERSAL MEASURES**
- HOB 30 degrees
- Cardiopulmonary homeostasis and euvolemia
- Maintenance of normothermia
- Adequate modality for ICP measurement
- Identify cause(s) of raised ICP or reduced CPP

**Hyperventilation**
- Goal: PCO₂ 25 – 30mmHg for < 30min

**CSF Drainage**
HUP NeuroICU
Comprehensive Osmotherapy Guidelines
Standard Monitoring: Tip of the Iceberg

Exam+ICP+CPP
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Accessible Physiology

• **Pressure**: ICP, CPP - EVD, fiberoptic probes

• **Flow**: CBF probes, Xe CT, CTP, MRP, TCD, NIRS

• **Oxygenation**: PbtO$_2$ (Licox), SjVO$_2$ (JBC)

• **Metabolism**: Cerebral Microdialysis, PET

• **Function**: continuous EEG, SSEP, BAEP
Cerebral Blood Flow
Brain Oxygenation

• Global Monitors
  • Jugular Venous Oxygen Saturation (SjvO$_2$)
    • Jugular bulb catheter

• Regional Monitors
  • Brain tissue oxygen partial pressure (PbtO$_2$)
    • 2 commercially available probes (Licox, Paratrend)
Cerebral Venous Oxygen Saturation (SjvO$_2$) monitoring

- Measured via jugular bulb catheter
- Assesses **global** balance of brain O$_2$ supply and demand
- Analogous to a mixed venous gas from a PA catheter
- Normal SjvO$_2$ range is 60% to 80%
- Therapy for abnormal SjvO$_2$ is cause-specific
SjvO_2 Interpretation

**Low SjvO_2 (<50%):**
- Low DO_2
  - Arterial hypoxemia
  - Anemia
  - Low CBF (ischemia)
- Increased CMRO2
- Fever
- Seizures

**High SjvO_2 (> 85%):**
- High DO_2
  - Hyperemia
  - Decreased CMRO2
  - Failure of oxygen extraction
- SjvO_2 \sim \frac{DO_2}{CMRO_2}
Brain Tissue O$_2$ Tension

• Small probe (Licox) inserted into brain tissue

• Measures partial pressure of oxygen (PbtO$_2$) in interstitial space
  • Normal: > 30 mmHg
  • Hypoxia: < 15 mmHg
  • Cell Death: < 5 mmHg
  • Treatment Threshold: < 20 mmHg
Licox in Situ
Low PbtO2 - Treatment

- Inadequate blood flow
  - Micro- or macrocirculatory dysfunction
- Reduced blood oxygen content
  - Anemia
  - Systemic hypoxemia
- Impaired diffusion of oxygen
  - ?? cerebral edema
- Increased cellular consumption
  - Ischemia, fever, seizures, trauma

• Volume resuscitation, vasopressors, inotropes
• Lowering ICP - osmotherapy, craniectomy
• Red blood cell transfusion, correction of hypoxemia
• Treatment of seizures, fever, rigors
• Metabolic therapy - hypothermia, barbiturates
Does PbtO$_2$ Treatment Make a Difference?

- It is likely that low PbtO2 is associated with poor outcome.
- Whether PbtO2-targeted therapy improves outcome has yet to be definitively established.
  - No prospective RCT
  - There are retrospective data
PbtO2-directed Therapy and Outcome after Severe TBI

To assess the impact of brain tissue PO2-guided therapy, we determined whether there was improved survival and disposition at the time of hospital discharge. Eleven (44%) of the 25 patients who had undergone conventional ICP and CPP management died (Fig. 1). In contrast, 30% of patients with PbtO2-directed treatment was associated with improved survival: that is, seven (31%) of these 28 patients died ($p < 0.05$). Furthermore, 17% of surviving patients (4 patients) who had undergone ICP and CPP-guided management required additional hospitalization or nursing home placement (Fig. 2). None of the survivors (21 patients) in the brain tissue PO2-guided group required nursing home placement; all were discharged to either a home or a rehabilitation center.

**Brain O2 and Patient Outcome**

Among patients who had undergone brain tissue PO2-directed treatment, cerebral hypoxia episodes ($<15$ mm Hg) were more frequent in those who died ($1.23 \pm 1$) than in those who survived ($0.34 \pm 8$; $p = 0.007$). In addition, the cumulative duration of compromised cerebral oxygenation ($<22$ mm Hg) was significantly longer in those who died ($364.9 \pm 422.7$ minutes) than in survivors ($104.9 \pm 362.9$ minutes; $p = 0.04$).

**Discussion**

In this study consisting of 53 patients with severe TBI, we determined how a management strategy that included brain tissue PO2 monitoring influenced the patient mortality rate at a Level I trauma center. Thus, we compared the outcomes among 28 patients who had been treated using ICP and brain tissue PO2 monitoring with those in 25 matched historical controls treated with an ICP monitor alone. Our results demonstrate that brain tissue PO2 monitoring was associated with a significant reduction in patient deaths.

**Methodological Limitations**

Data in this study were collected prospectively in an observational database and have two major limitations. First, the small sample size—53—means that our results should be regarded as preliminary but as nonetheless useful information in clinical practice or in designing further trials. Consider, for example, that prophylactic hyperventilation is not recommended to TBI management. However, this standard is based on a study that included 77 patients randomized to undergo either hyperventilation or normal ventilation. Second, our study design is nonrandomized and represents historical controls. Note, however, that the same team of physicians and nurses in the same ICU provided patient care during the entire study period. In addition, treatment was not changed during the study period except for the introduction of brain tissue PO2 monitoring and brain tissue PO2-based therapy. We carefully matched patients for age, admission GCS score, ISS, and pathological entity. We have therefore that our results indicate a beneficial effect. Ideally, a randomized clinical trial is necessary. Before such a trial, however, sufficient clinical data are needed to justify and plan for such an undertaking. It is interesting to note that the impact of ICP monitoring on patient outcome has yet to be directly evaluated, including in a randomized clinical trial.

**Monitoring ICP**

Monitoring ICP has become routine in many neurointensive care units and is recommended in patients with severe TBI. Although the benefit of ICP monitoring has not been demonstrated in any clinical trial, the association between increased ICP and poor outcome has been well described. The primary reason to treat increased ICP ($>20$ mm Hg) is to maintain adequate CPP and thus prevent cerebral ischemia or infarction, which adversely affects patient outcome. Note, however, that increased CPP is responsible for less than half the episodes of cerebral ischemia, and cerebral infarction can occur despite normal ICP and CPP. Furthermore, data from recent positron emission tomography studies demonstrate that in some patients with TBI, mechanisms other than simple perfusion-related ischemia may be responsible for cellular hypoxia in the brain.

Brain Metabolism

- **Global**
  - \( \text{CMR}_X = (A_x - V_{Jx}) \times \text{CBF} \)

- **Regional**
  - **Microdialysis**
    - Energy-related metabolites (glucose, lactate, pyruvate)
    - Markers of neuronal injury (glycerol, glutamate)
    - Neurotransmitters (glutamate, aspartate)
    - Exogenous substances (drugs)
Principles of Cerebral Microdialysis

- Blood capillary
- Small molecules
- Uptake into catheter
- Release from cells
- Micro-dialysis catheter
Patient: TBI - s/p SDH evacuation

LPR > 40, ICP nl, CT performed

LPR normalizes

Pt remains comatose
LPR trending up

EDH evacuated!

CMD catheter in tissue at risk

Pt remains comatose
Meanwhile . . . In the Contralateral Hemisphere:
Functional Monitoring

- Continuous EEG (cEEG)
- Subclinical seizures
- Ischemia detection
- Drug titration
- Prognosis
Seizures and cEEG

• Seizures are a form of secondary brain injury.
• Seizures are common in the critically-ill population
• In NeuroICU, ~35% have non-convulsive seizures
  • 75% of these are non-convulsive status epilepticus
• cEEG identifies clinically silent seizures

Seizure Detection Algorithm

Total Power Trend Analysis (6-14 Hz)

Average power (μV²) over compressed time periods
Seizure Detection Algorithm
Compressed Spectral Array: Frequency analysis
cEEG and Ischemia

- Brain waves:
  - Beta: >16 Hz
  - Alpha: 9-12 Hz
  - Theta: 5-8 Hz
  - Delta: 0-4 Hz

- With ischemia: more delta, less alpha

Ischemia Detection
Patient MK: EEG tracing with good alpha variability
Patient MK: EEG tracing with poor alpha variability
Patient MK: graphical display of alpha variability

OK ← ISCHEMIA
cEEG

• In many ways, cEEG is an ideal NeuroICU monitor
  • Continuous
  • Non-invasive
  • Functional data
  • Regional and global information
Parting Thoughts

• Survival after critical illness is not meaningful without acceptable neurological function.

• Secondary injury occurs after acute injury and is the target of treatment.

• No single method of monitoring is sufficient to detect secondary injury. Use multiple methods.

• Understand the rationale behind treatment algorithms and use them appropriately.
Thank You

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