MULTIMODALITY MONITORING
An Overview

Stephan A Mayer, MD

Neurological Intensive Care Unit
NY Presbyterian Hospital, Columbia-Presbyterian Center
Columbia University College of Physicians & Surgeons
ORIGINAL MOTION PICTURE SOUNDTRACK
MUSIC COMPOSED AND CONDUCTED BY JERRY GOLDSMITH

COMA

BCD 3027
(A22721)
Three Phases of the History of Neuromonitoring

• Phase 1: Clinical neuromonitoring
  • 1960-1980
  • React to clinical events
Sternal Rub
Intracranial Mass Effect
Three Phases of the History of Neuromonitoring

- Phase 1: Clinical neuromonitoring
  - 1960-1980
  - React to clinical events
- Phase 2: **Physiological** neuromonitoring
  - 1980-2000
  - React to **pathophysiological** events
Three Phases of the History of Neuromonitoring

- **Phase 1:** Clinical neuromonitoring
  - 1960-1980
  - React to clinical events
- **Phase 2:** Physiological neuromonitoring
  - 1980-2000
  - React to pathophysiologically events
- **Phase 3:** Neurophysiological BRAIN support
  - 21st Century
  - Understand and manage complex physiology to prevent pathophysiologically events
Richard BERRY

THE BLACK BON

written by Eric ASSOUS and Richard BERRY

based on the short story "I'm here now" by Tommo BENACQUISTA
Good-grade patient: Steer by exam
Poor-grade patient: Steer by gauges

 Courtesy J Michael Schmidt PhD
Neuro-ICU Brain Monitoring

- ICP
- cEEG
- CBF
- SJVO2
- TCD
- Brain Tissue O2
- Microdialysis

COURTESY DR PAUL VESPA
Multimodal monitoring during hypothermia

anisocoria: l>r
Hetastarch
Glycerol
Thiopental
Mannitol
THAM
Body positioning

COURTESY DR THORSTEN STEINER
ICP: Dead End Box
Integrated NICU Monitoring System of the Future

- cEEG
- ICP/CPP
- TCD/CBF
- JVO2 sat/AVDO2
- Brain Tissue Oxygenation
- Intracerebral Microdialysis

Chaos and Confusion

- BP
- CI
- Temp
- pO2
- ETCO2
- Sedation

COURTESY DR MICHAEL DEGEORGIA
Integrated NICU Multimodality System of the Future

Physiologic Brain Health
- cEEG
- ICP/CPP
- TCD/CBF
- JVO2 sat/AVDO2
- Brain Tissue Oxygenation
- Intracerebral Microdialysis

Physiologic Drivers
- BP
- CI
- Temp
- FiO2
- ETCO2
- Sedation

Integrated NICU Monitoring System

Event Monitoring
Real Time Physiologic Interrelationships
Post Hoc “Data Mining”

NICU Records

ADAPTED COURTESY OF DR MICHAEL DEGEORGIA
Real Time Physiologic Interrelationships
Brain Oxygen Tension Monitoring: LICOX
**Licox Sensor**

- Probe properties
  - Solid tip for tissue displacement
  - Clark electrode (battery)
  - $pO_2$ sensitive area is 14 mm$^3$
  - Normal Pbr$O_2$ 40 mm Hg
Effect of Brain Tissue Hypoxia on Outcome
Subarachnoid Hemorrhage

DURATION OF CRITICAL HYPOXIA: <10 MM HG

Good Outcome

Poor Outcome

<30 minutes

65%

35%

>30 minutes

23%

77%  

P=0.05

Kett-White R et al. Neurosurgery.2001;50; 1213-21
LICOX

- PbrO2 Levels Integrate Oxygen
  - DELIVERY  CPP/MAP
  - DIFFUSION  Osmotherapy
  - CONSUMPTION  Sedation, Cooling

- Variables that Influence Blood O2 Content
  - FiO2
  - Hemoglobin
Scatterplot of Cerebral Perfusion Pressure by Brain Oxygen
Time Period 900-1000 Minutes
\[ r^2 = 0.6934 \]
Cerebral Autoregulation

Adapted with permission from Varon J, Marik PE. Chest. 2000;118:214-227.
Cerebral Microdialysis

DIALYSATE IN
BRAIN
RECEPTACLE: Dialysate Out

DIALYSATE OUT

PUMP

CMA 107 Microdialysis Pump
MICRODIALYSIS

- FDA & EU APPROVED
  - GLUCOSE
  - LACTATE
  - PYRUVATE
- EU APPROVED
  - GLYCEROL
  - GLUTAMATE
Brain lactate/pyruvate ratios **INCREASE** in injured tissue when CPP if critically compromised below 50 mm Hg

![Lactate/pyruvate Ratio Chart]

- **<50 mm Hg**: n:367, ±15
- **50-60 mm Hg**: n:592, ±14
- **61-70 mm Hg**: n:1138, ±10
- **>70 mm Hg**: n:1552, ±10

Note: The ± values indicate the standard deviation.
Increase in extracellular LPR with nonconvulsive seizures

LPR in seizure patients, 
n = 9 pts, k = 108 hours

COURTESY PAUL VESPA, MD
NEUROMONITORING BUNDLE

TRIPLE LUMEN BOLT
- ICP
- LICOX
- MICRODIALYSIS

Burr Hole
- EEG DEPTH ELECTRODE
- HEMEDEX (BOWMAN) CBF
DISCOVERIES
Based on Multimodality Monitoring
Columbia Neuro-ICU

2006 – 2012
N = 140
PbtO2 often passively varies with fluctuations in CPP and can serve as an endpoint for goal-directed therapy.


Metabolic Crisis and Brain Tissue Hypoxia *Increase* when CPP is <70 mm Hg in Poor-Grade SAH

Brain Tissue Hypoxia and Metabolic Crisis Increase with Lower CPP in Comatose Patients with ICH

IMAGING AUTOREGULATORY FAILURE AND ITS NORMALIZATION
Comatose ICH Survivors: Lower ICP & LPR, Higher CPP & PbtO2

A. Cerebral perfusion pressure (mm Hg)
B. Intracranial pressure (mm Hg)
C. PbtO2 (mm Hg)
D. Lactate/pyruvate ratio

Ko S. et al: Multimodality Monitoring for Cerebral Perfusion Pressure Optimization In Comatose Patients with Intracerebral Hemorrhage. (in preparation)
The “best practice” of intensive insulin infusion for tight glycemic control in brain injured patients is associated with critical brain hypoglycemia.

Figure 1.
Kurtz, et al: **Reduced Brain/Serum Glucose Ratios Predict Metabolic Distress and Mortality after Severe Brain Injury.** Int Care Med (submitted)
Fever reduces brain tissue oxygen levels – but cooling with inadequate control of shivering makes the brain hypoxia even worse!

Oddo M, Bajjatia N et al. Effect of induced cooling on brain tissue oxygenation after severe brain injury (in preparation)
Impact of Shiver control on brain oxygenation

Before fentanyl

After fentanyl

Arctic Sun Water Temperature

$P_bO_2$
Brain hypoxia is increased with induced normothermia

Columbia Anti-Shivering Protocol

Emphasizes skin counterwarming and magnesium ➔
dexmedetomidine ➔ conventional analgosedation
Severe unintentional central hyperventilation is a common and unrecognized of critical brain tissue hypoxia.
Frequency of Brain Tissue Hypoxia (PbtO2 < 15 mmHg) Related to Concurrent EtCO2

- <25 mmHg (N=254)
- 25-29 mmHg (N=468)
- 30-34 mmHg (N=634)
- 35-44 mmHg (N=781)
- ≥45 mmHg (N=121)
Mild levels of anemia considered acceptable in MICU patients are associated with reduced brain tissue oxygen levels in neurological patients.

Brain Tissue Hypoxia and Metabolic Crisis is Associated With Hb Levels <8.0 mg/dl
Insertion of an EEG depth electrode in comatose patients reveals previously “hidden” seizure activity in one-third of patients

Seizures on the depth without scalp correlate
74 yo woman with SAH (HH grade III)
Ability of surface EEG to detect depth TCME findings

Surface EEG correlate
- None
- Intermittently present
- Consistently present

Depth EEG findings

Seizures (10 of 16)
- None: 1
- Intermittently present: 4
- Consistently present: 5

PEDs (2 of 16)
- None: 1
- Intermittently present: 1

No epileptiform activity (4 of 16)
80 year-old man s/p PEA arrest GCS-3 with bilateral eye twitching

MAP
CPP
ICP
Brain Temp
rCBF
PBTO2
EEG-power
ETCO2
HR
Keppra
27 year old man with asthma leading to respiratory failure and cardiac arrest
Initially, the background demonstrates diffuse suppression punctuated by generalized bursts corresponding clinically to myoclonus. Scalp electrodes are seen on top (sensitivity 7 µV/mm) and right frontal depth electrodes are seen in blue beneath (D1-D8; sensitivity 15 µV/mm). EKG is seen in red at the bottom (sensitivity 50 µV/mm). Depth electrodes D1 and D2 are likely in subcortical tissue.
Generalized myoclonic bursts occur in clusters both on scalp and in the depth electrodes.
Initially a repetitive run of myoclonus (myoclonic seizure), depth displays underlying rhythmic faster frequencies at D4 between seconds 12 and 14 of this EEG.
As the myoclonus stops, the depth demonstrates an evolving seizure pattern with rhythmic 8Hz theta-alpha spreading into adjacent electrodes (D5, D6). The scalp demonstrates a frontally-predominant rhythmic delta activity initially at 2Hz evolving to a less defined 1Hz before becoming polymorphic.
Depth seizure continues to evolve in amplitude and location, now involving all cortically-based electrodes. The scalp demonstrates quasi-rhythmic 0.5Hz delta but primarily non-rhythmic theta frequencies.
Here the depth seizure is interrupted briefly before resuming; with stuttering discharges in the depth, frontally predominant delta becomes more sharply contoured.
As the depth seizure becomes tightly organized briefly, there is pseudonormalization on the scalp recording (seconds 5-9) consisting of non-rhythmic diffuse theta; even delta frequencies are abolished.
The depth seizure finally ends with periodic discharges seen also on scalp; the background becomes suppressed once more. The first 5 hours, there were 121 of these events lasting 30-120s.
The Hemedex Thermal Conductivity CBF Monitor can be Used to Measure Brain Water Content

Components of the HEMEDEX System

Bowman Perfusion Monitor (BPM)  QFlow 500 Probe  Trending of CBF in ml/100mg/min
Physiological effects of Osmotherapy
(23.4% and 20% mannitol)
MMM Killer Apps

- Detect neuroworsening
- Optimize CPP
- Diagnose autoregulatory failure
- Identify and avoid excessive hyperventilation
- Detect seizures not evident on surface EEG
- Avoid critical brain hypoglycemia and anemia
- Identify secondary brain injury
Neurocritical Care Society

www.neurocriticalcare.org

JOIN ONLINE TODAY!