MULTIMODALITY MONITORING

An Overview

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NY Presbyterian Hospital, Columbia-Presbyterian Center
Columbia University College of Physiciansd & Surgeons

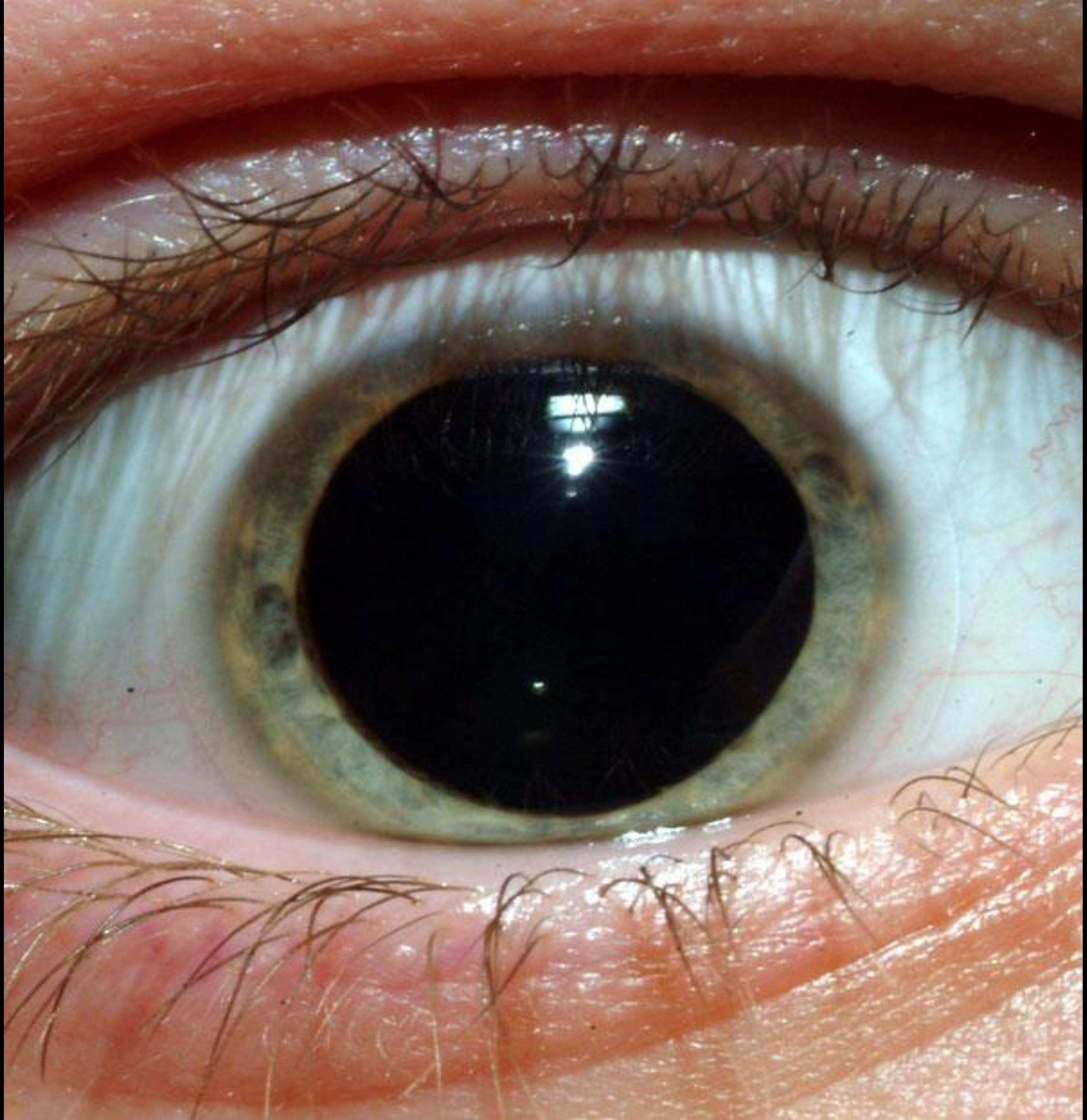

ORIGINAL MOTION PICTURE SOUNDTRACK
MUSIC COMPOSED AND CONDUCTED BY JERRY GOLDSMITH
COMA
Bay Cities
BCD 3027
(A22721)


NEURO
I.C.U.

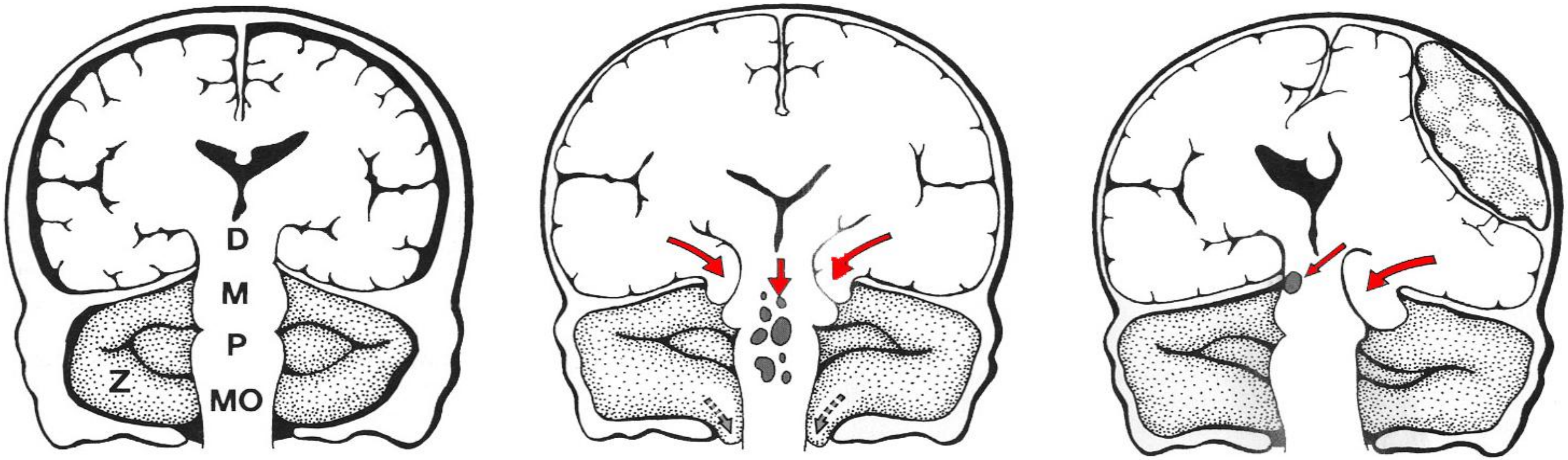
Three Phases of the History of Neuromonitoring

- Phase 1: Clinical neuromonitoring
  - 1960-1980
  - React to clinical events

Sternal Rub

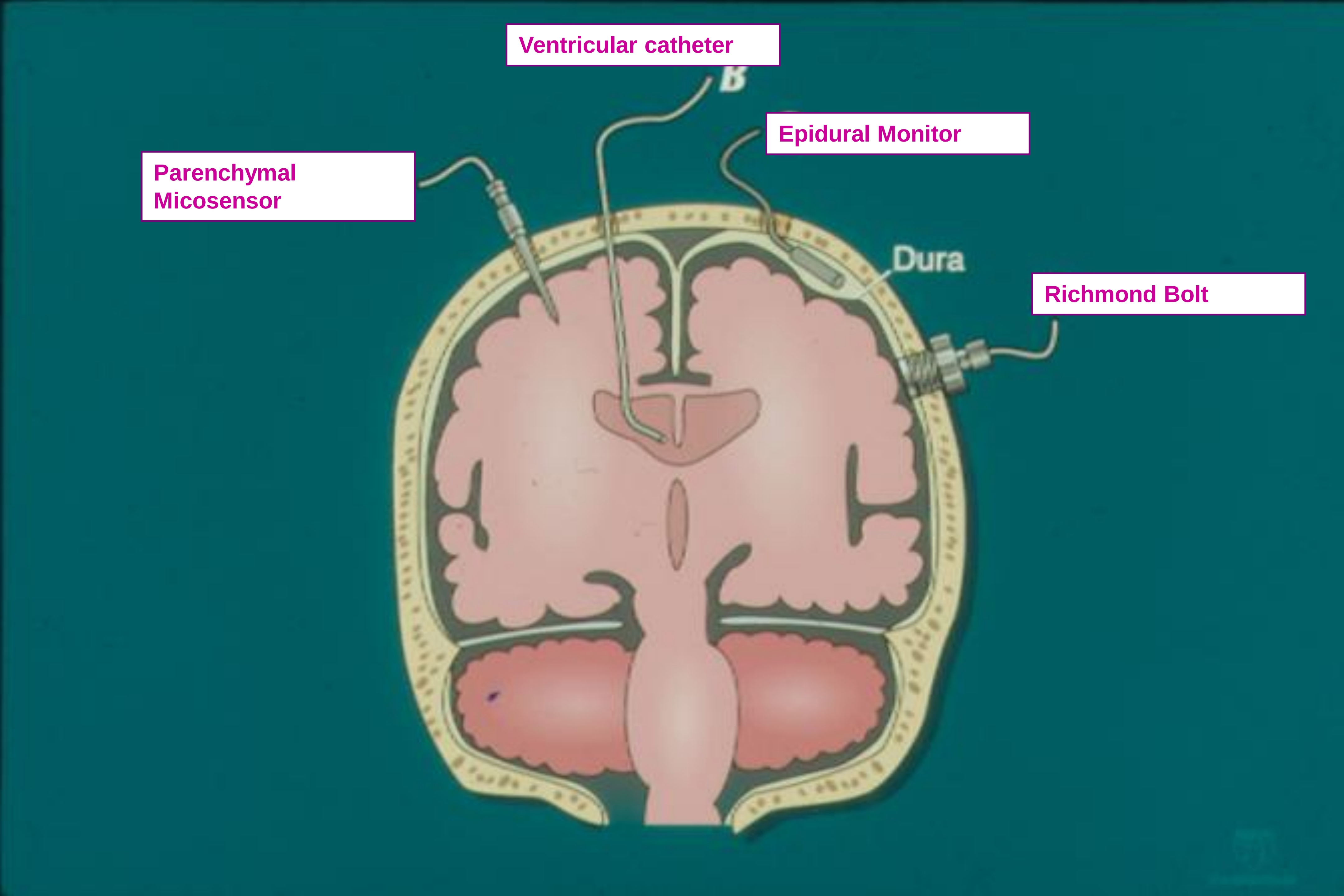


Intracranial Mass Effect

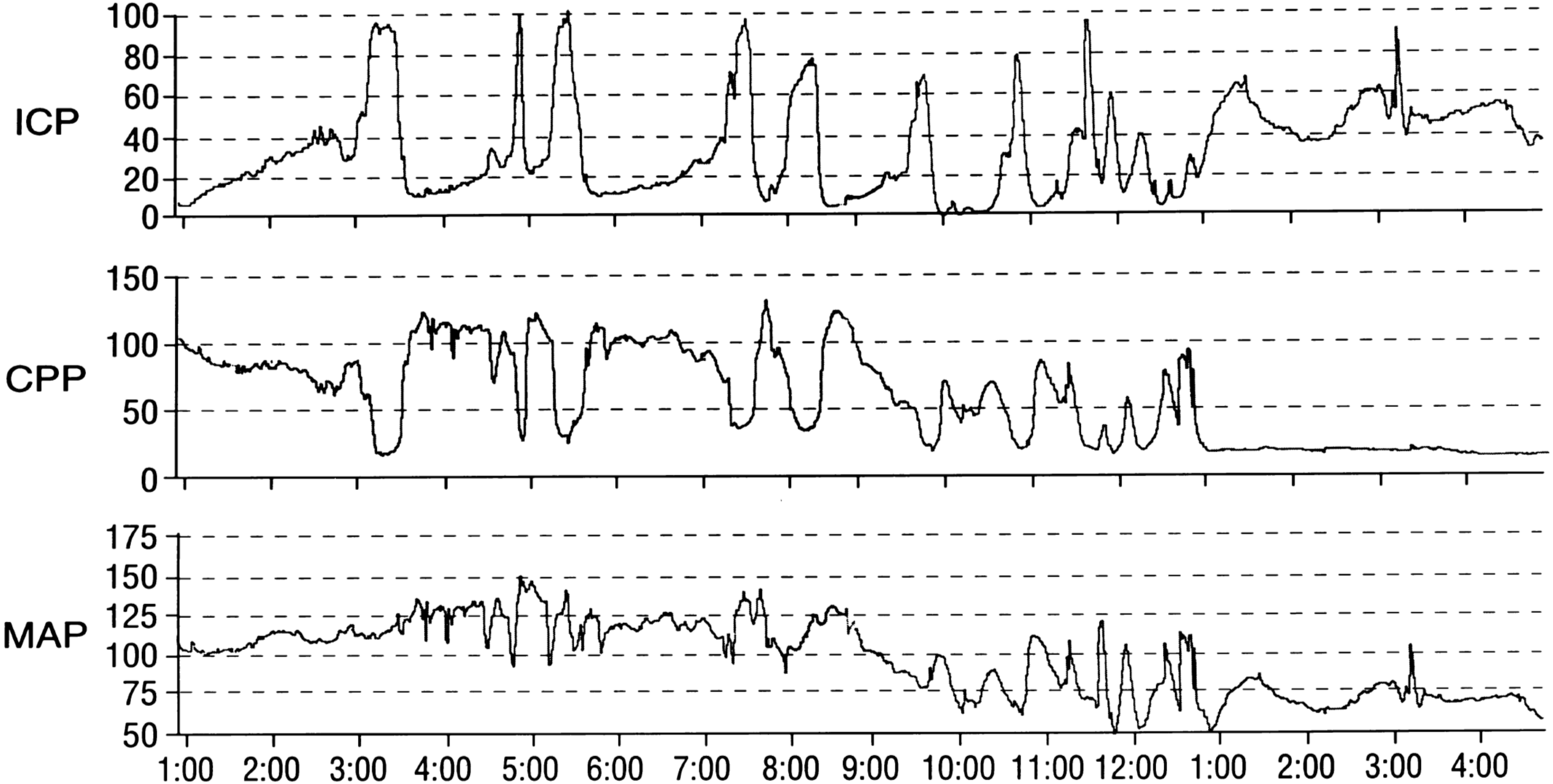


Three Phases of the History of Neuromonitoring

- Phase 1: Clinical neuromonitoring
  - 1960-1980
  - React to clinical events
- Phase 2: Physiological neuromonitoring
  - 1980-2000
  - React to pathophysiological events

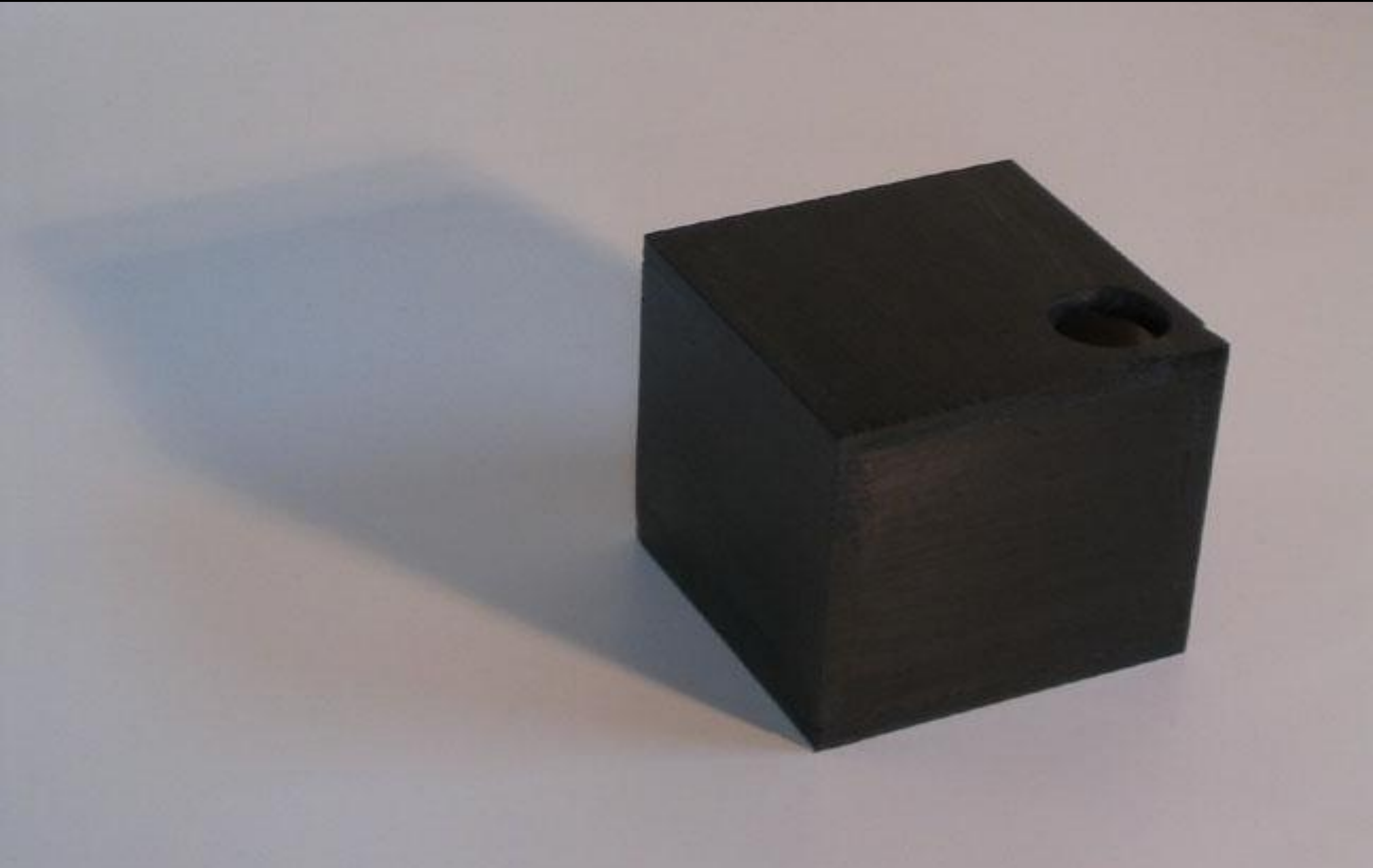


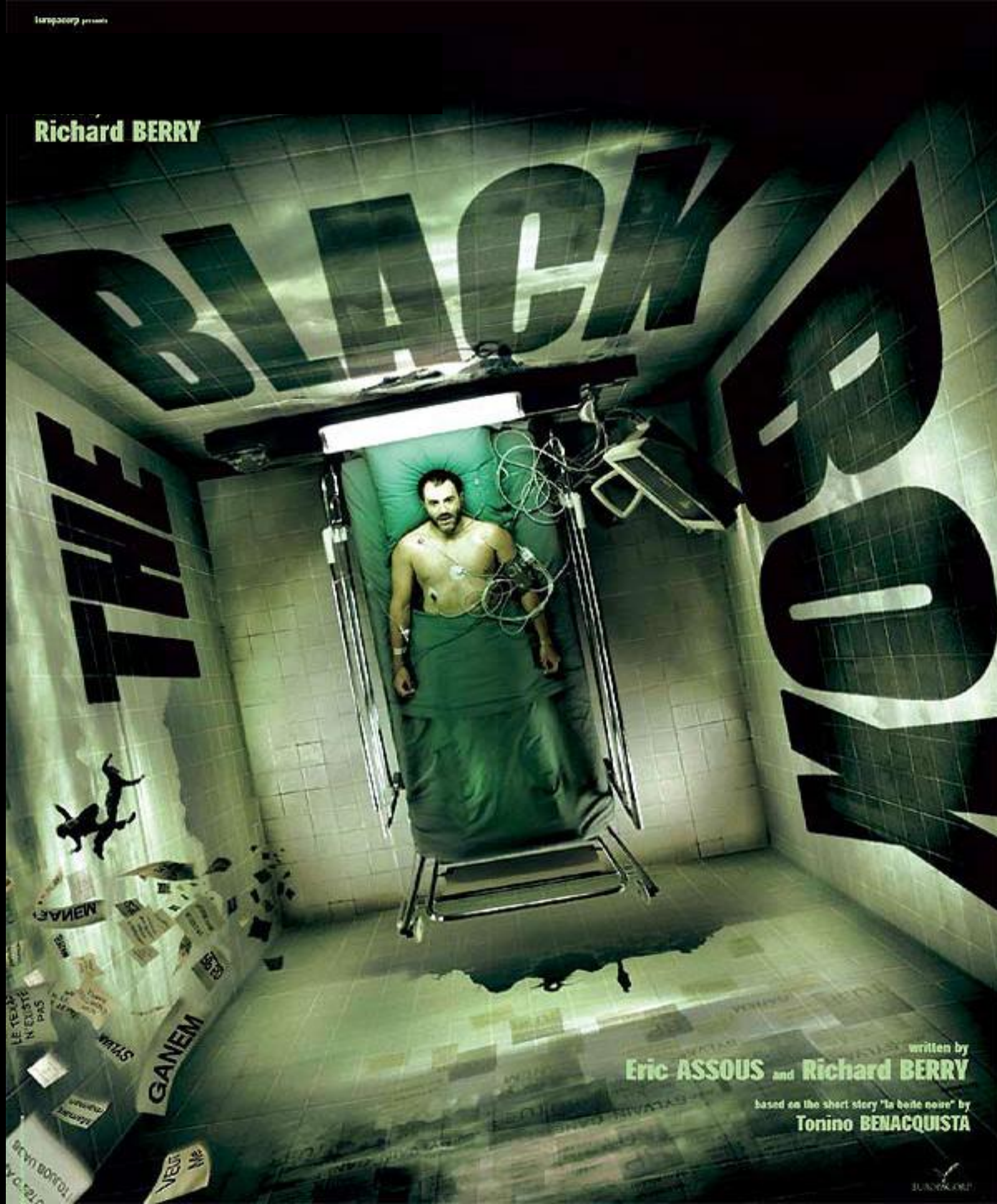
Ventricular catheter
B
Epidural Monitor
Parenchymal
Micosensor
Dura
Richmond Bolt


ICP
100
80
60
40
20
0
CPP
150
100
50
0
MAP
175
150
125
100
75
50
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00

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
- Phase 3: Neurophysiological BRAIN support
  - 21st Century
  - Understand and manage complex physiology to prevent pathophysiological events





Europacorp presents
Richard BERRY
THE BLACK BOX
written by
Eric ASSOUS and Richard BERRY
based on the short story "la boîte noire" by
Tonino BENACQUISTA

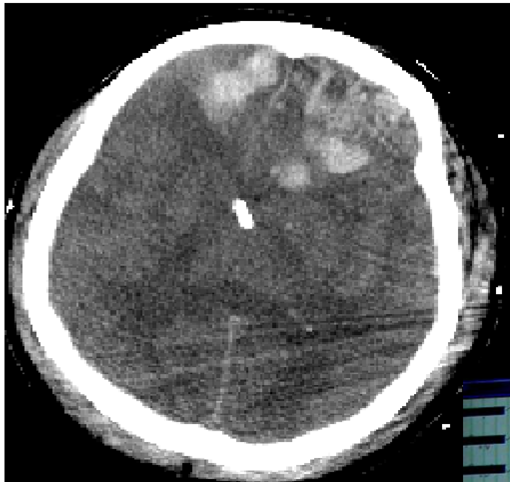
Good-grade patient: Steer by exam

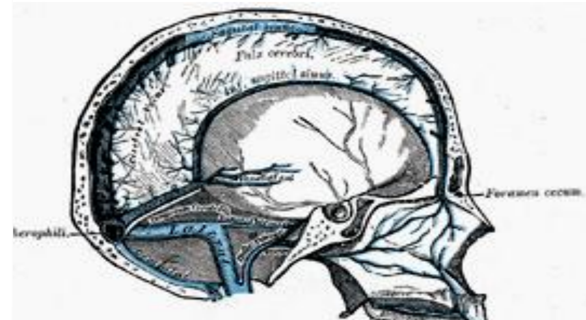
Poor-grade patient: Steer by gauges

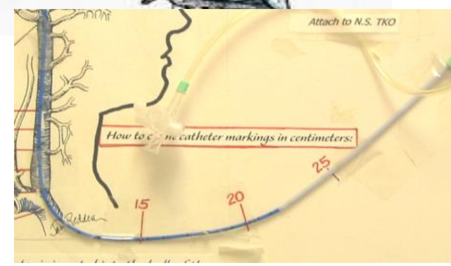
Courtesy J Michael Schmidt PhD

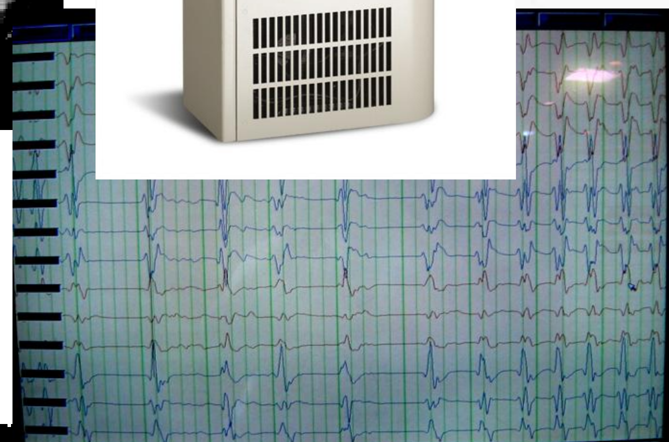
Neuro-ICU Brain Monitoring

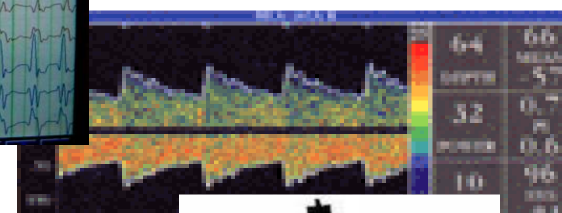
- ICP
- cEEG
- CBF
- SJVO2
- TCD
- Brain Tissue O2
- Microdialysis

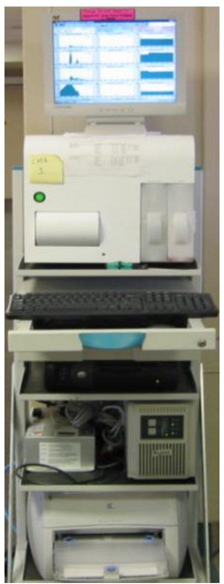


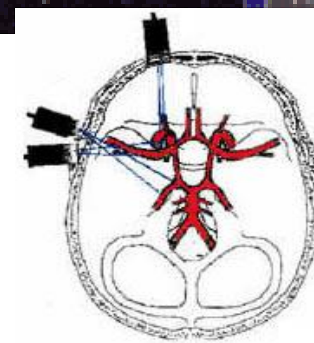






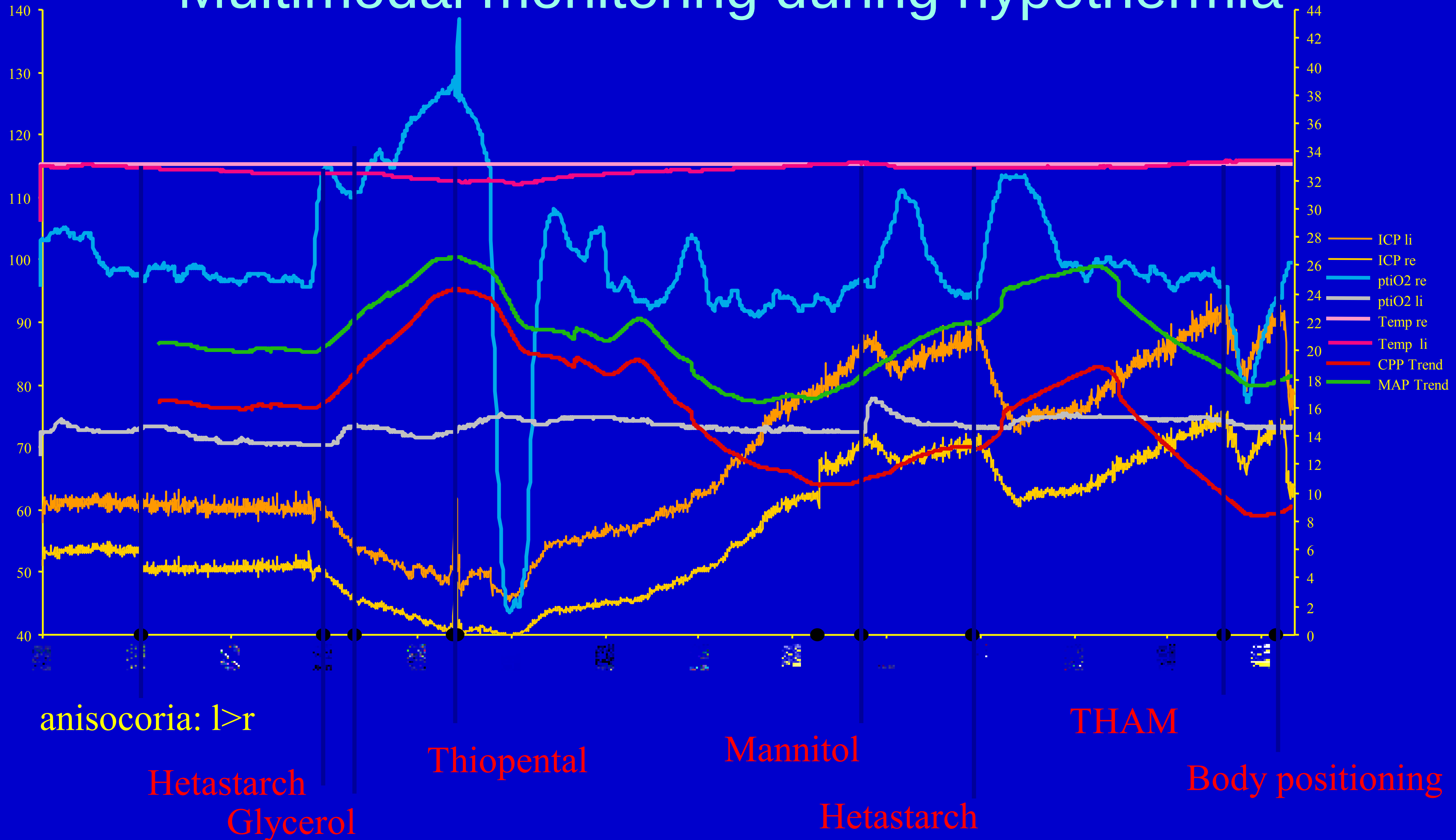






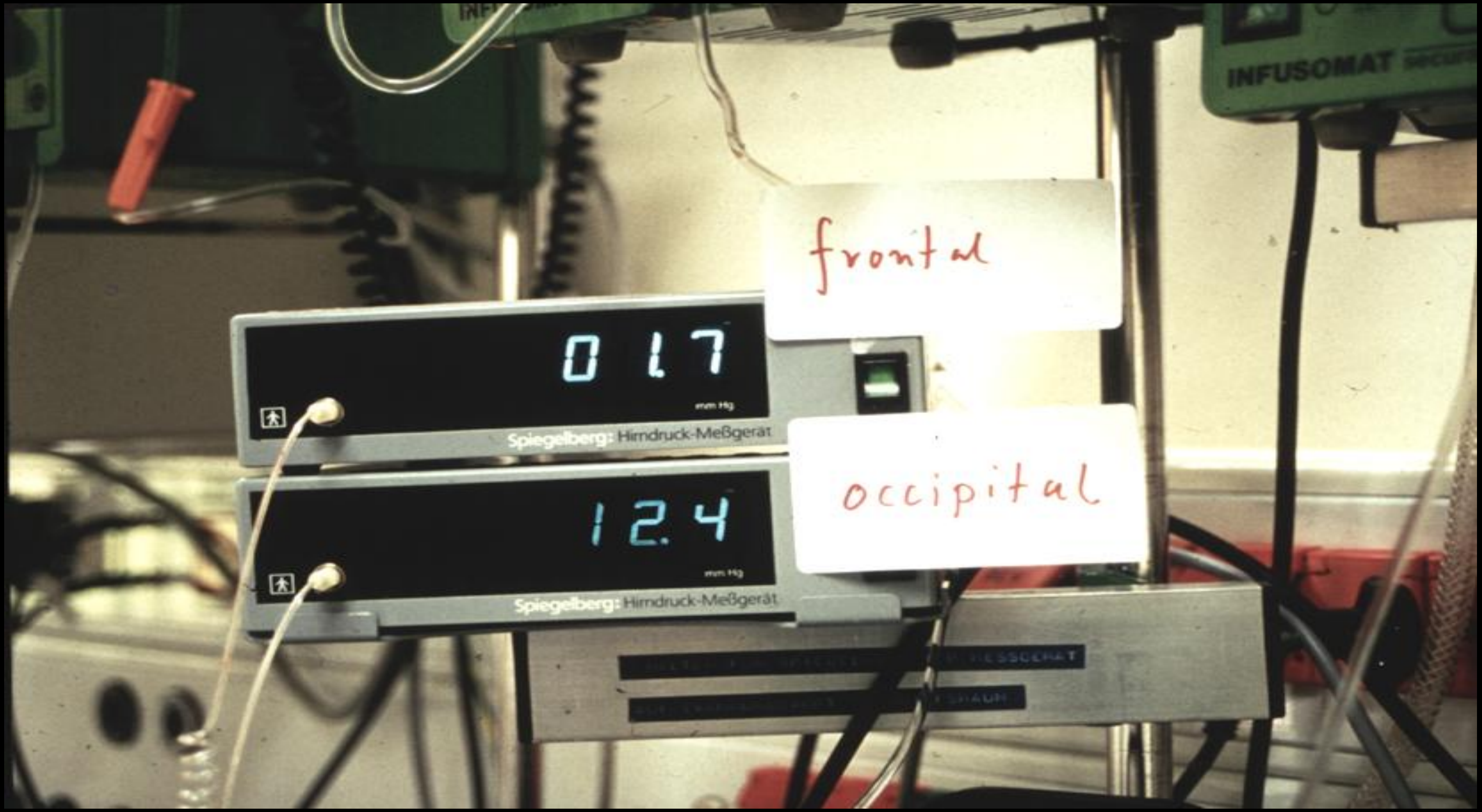
COURTESY DR PAUL VESPA

Multimodal monitoring during hypothermia

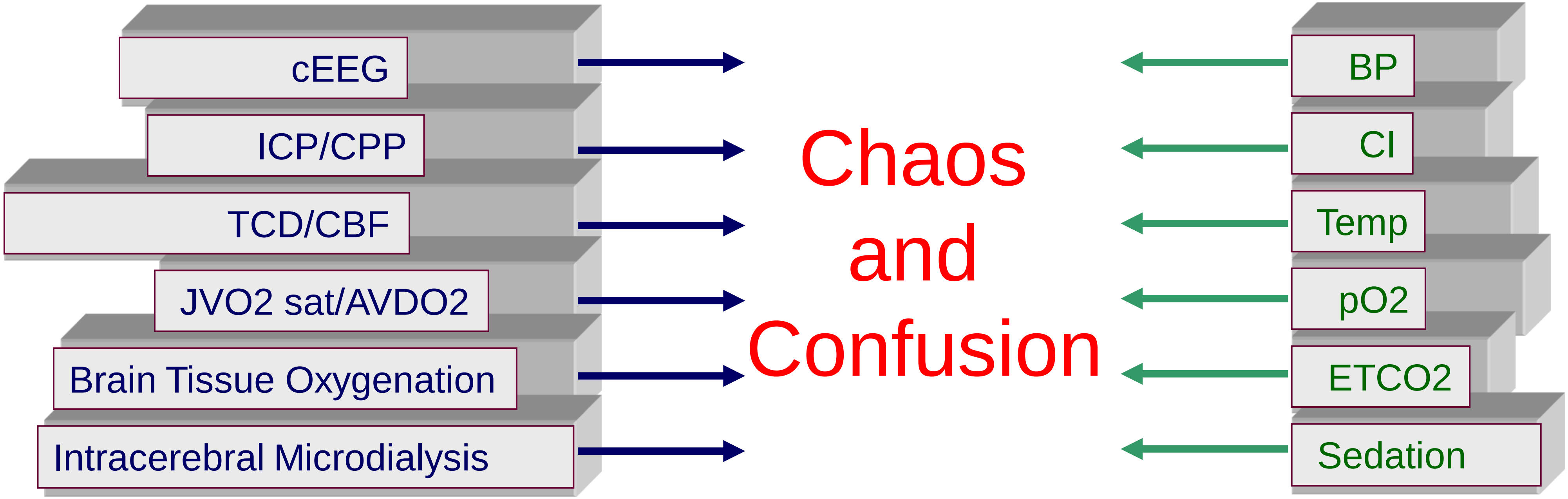


COURTESY DR THORSTEN STEINER

ICP: Dead End Box

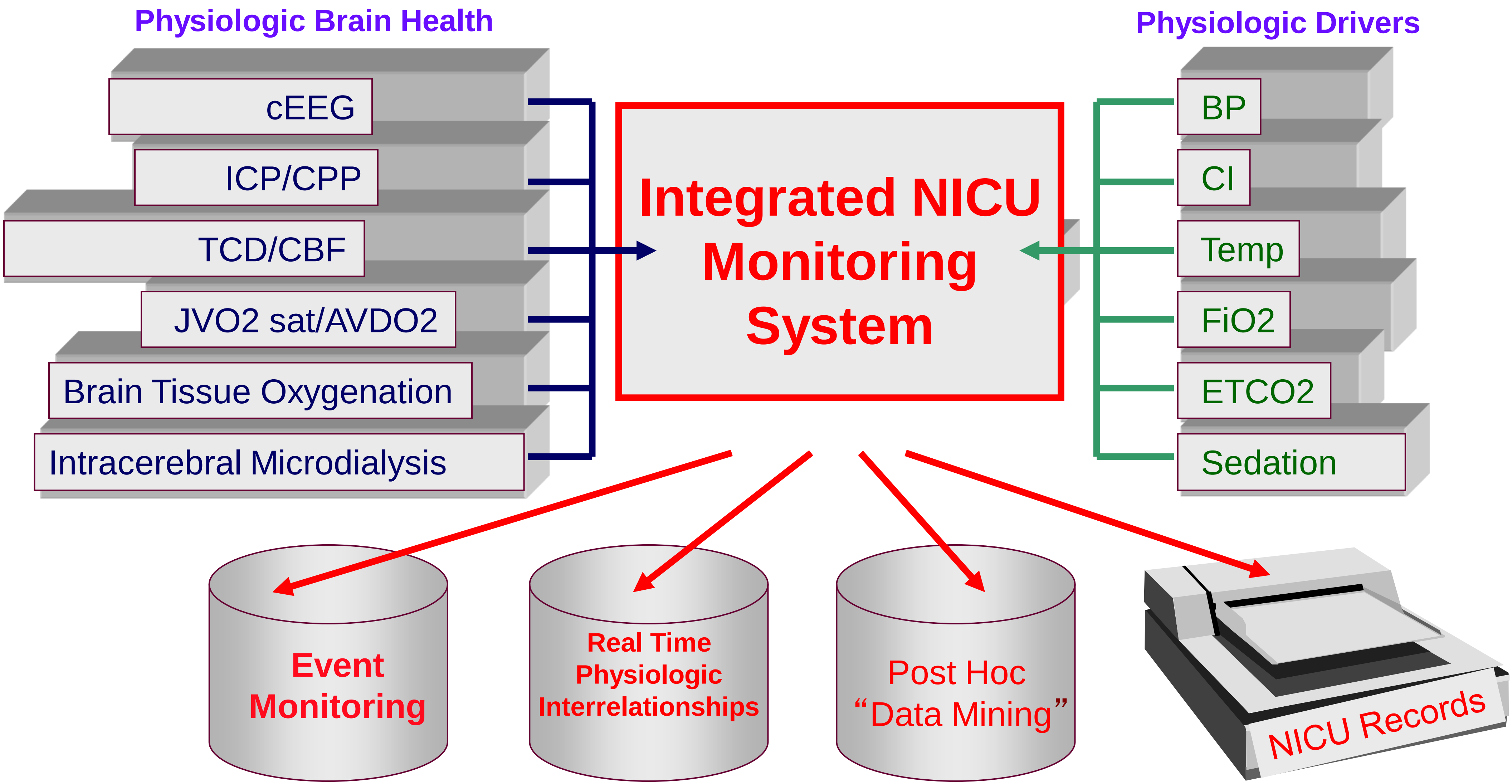


Integrated NICU Monitoring System of the Future

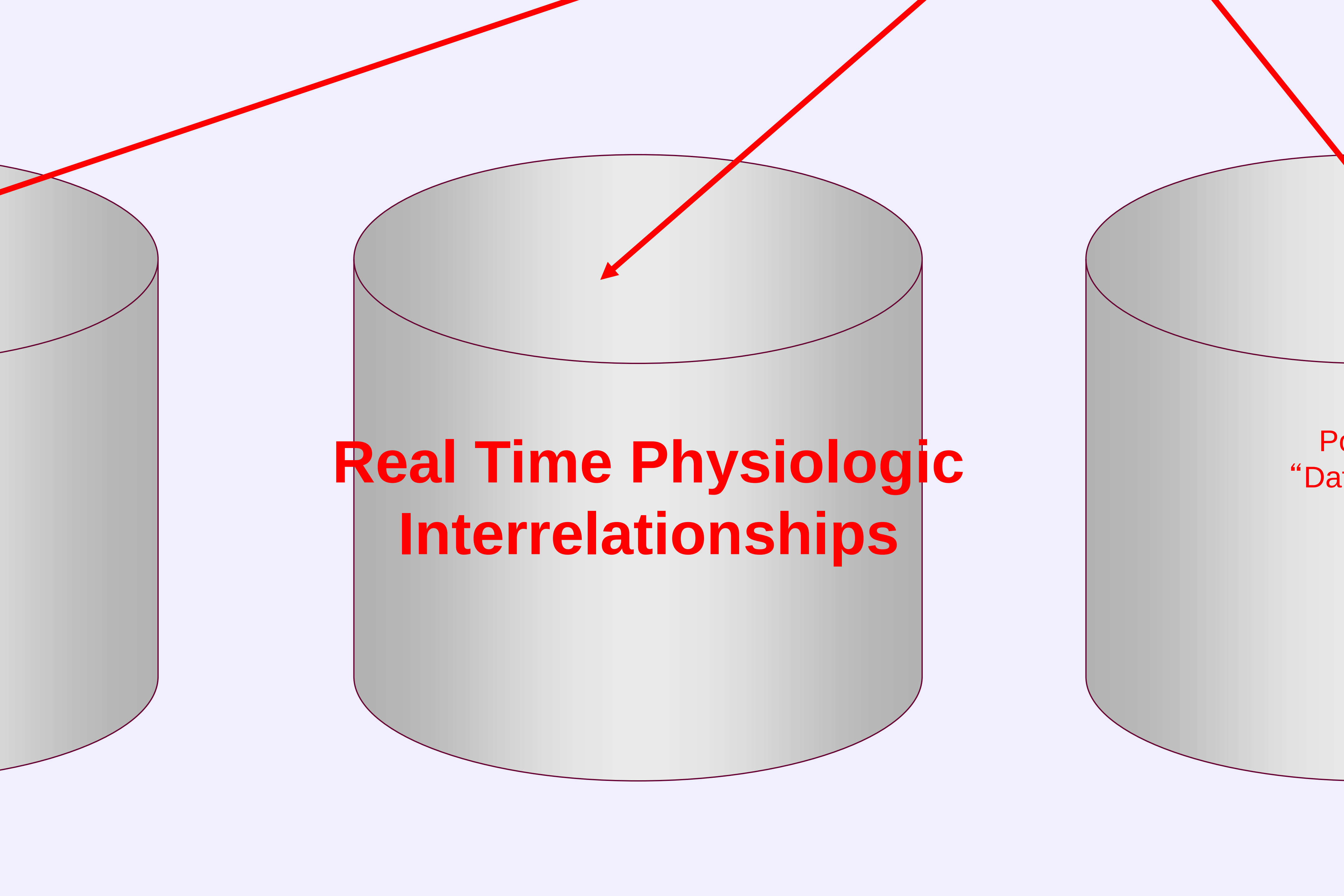


COURTESY DR MICHAEL DEGEORGIA

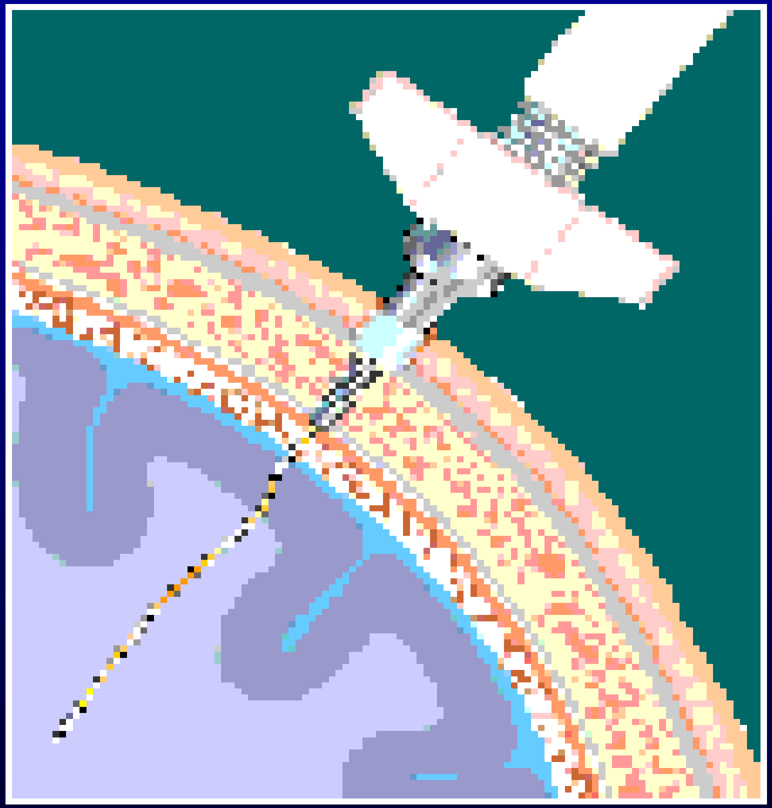
Integrated NICU Multimodality System of the Future



ADAPTED COURTESY OF DR MICHAEL DEGEORGIA

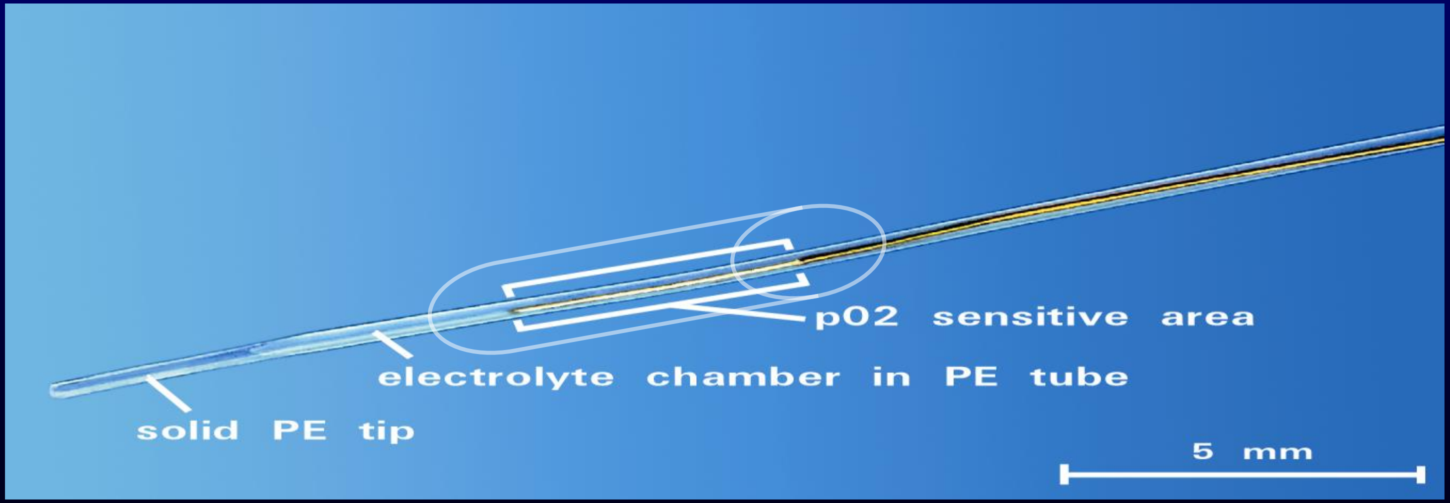

Real Time Physiologic
Interrelationships

Brain Oxygen Tension Monitoring: **LICOX**



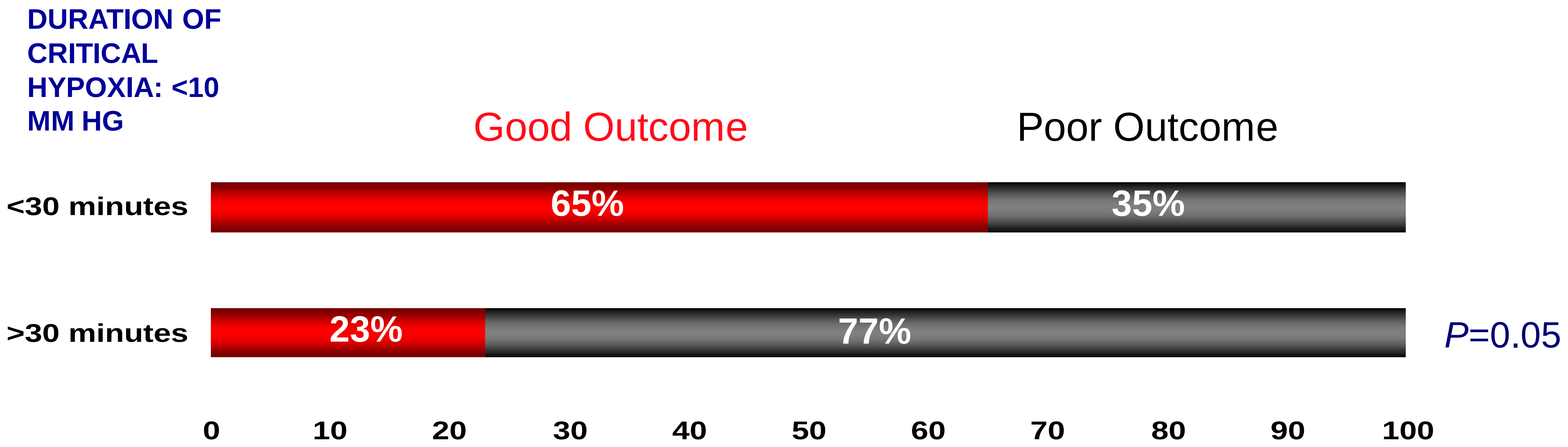
Licox Sensor

- Probe properties
  - Solid tip for tissue displacement
  - Clark electrode (battery)
  - **pO_2 sensitive area is 14 mm^3**
  - Normal $PbrO_2$ 40 mm Hg



Effect of Brain Tissue Hypoxia on Outcome

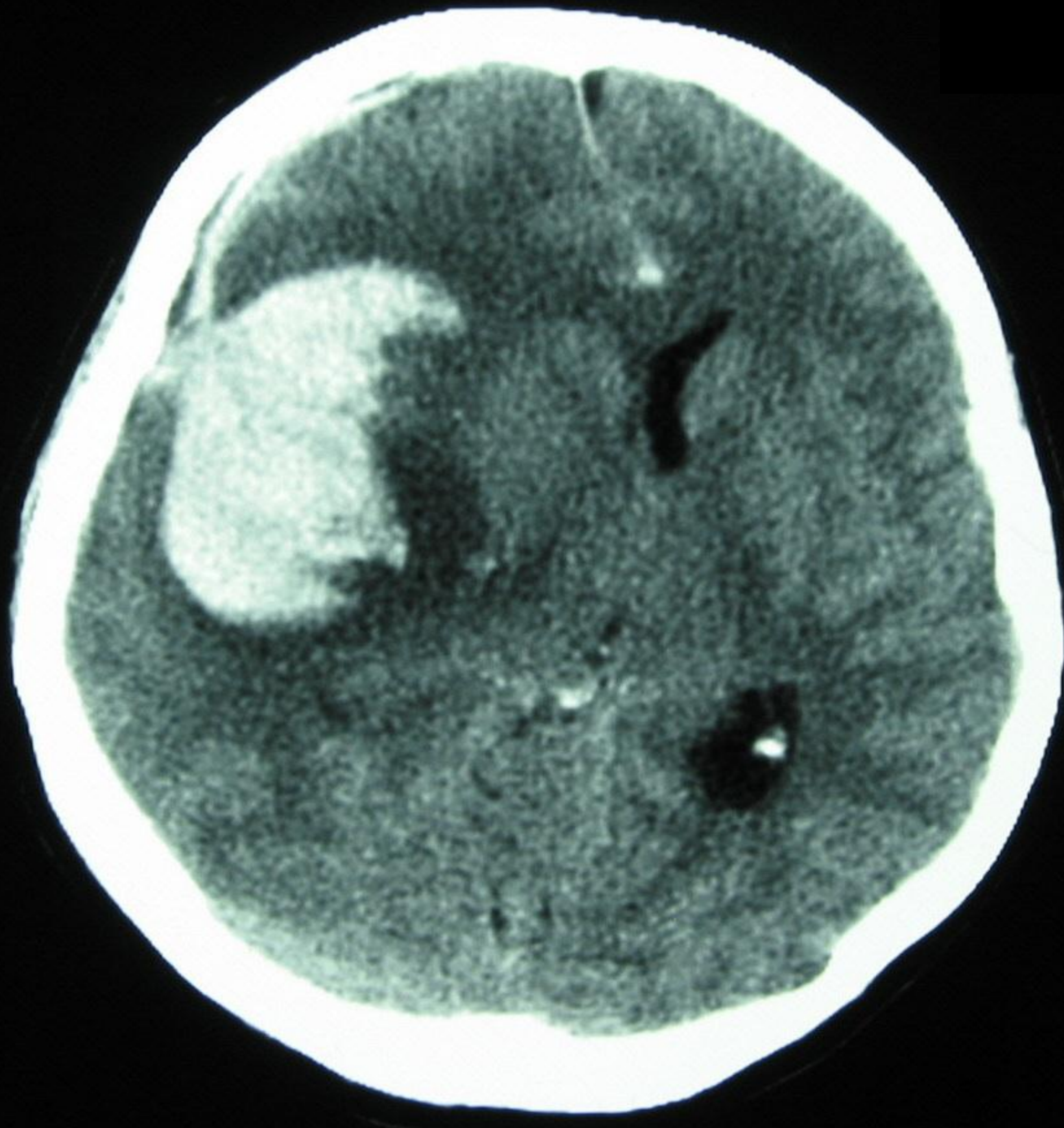
Subarachnoid Hemorrhage

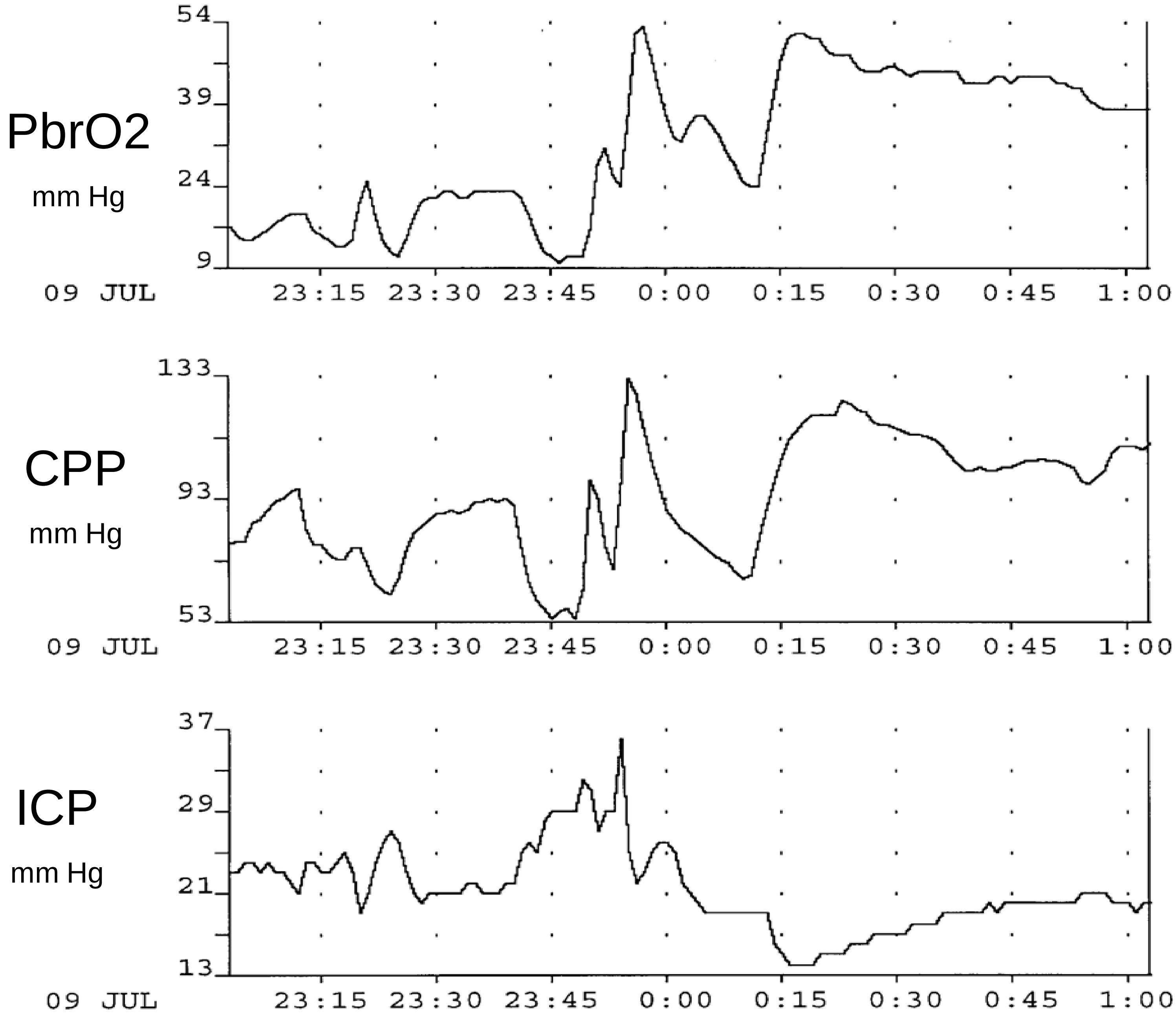


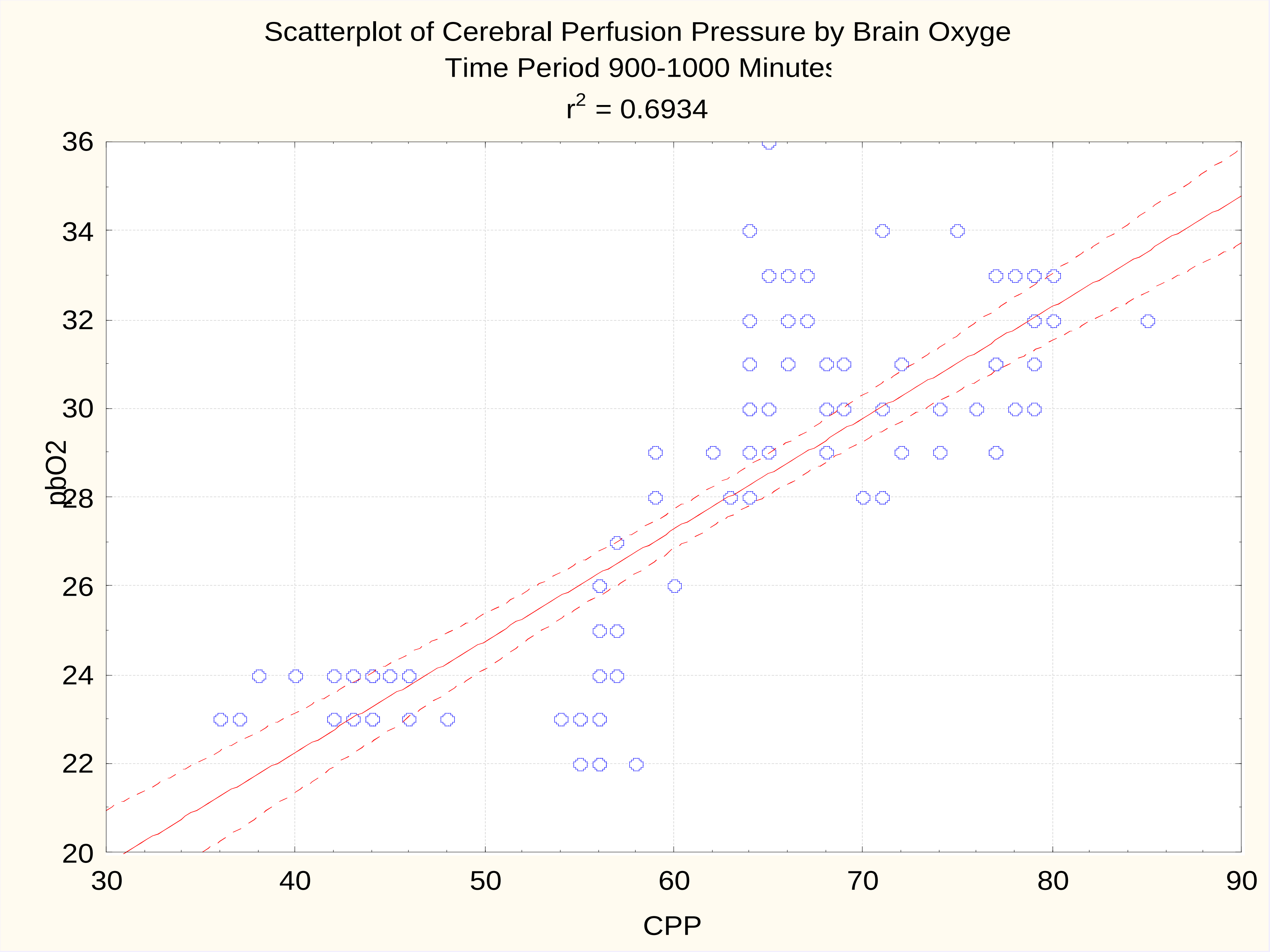
Kett-White R et al. Neurosurgery.2001;50; 1213-21

LICOX

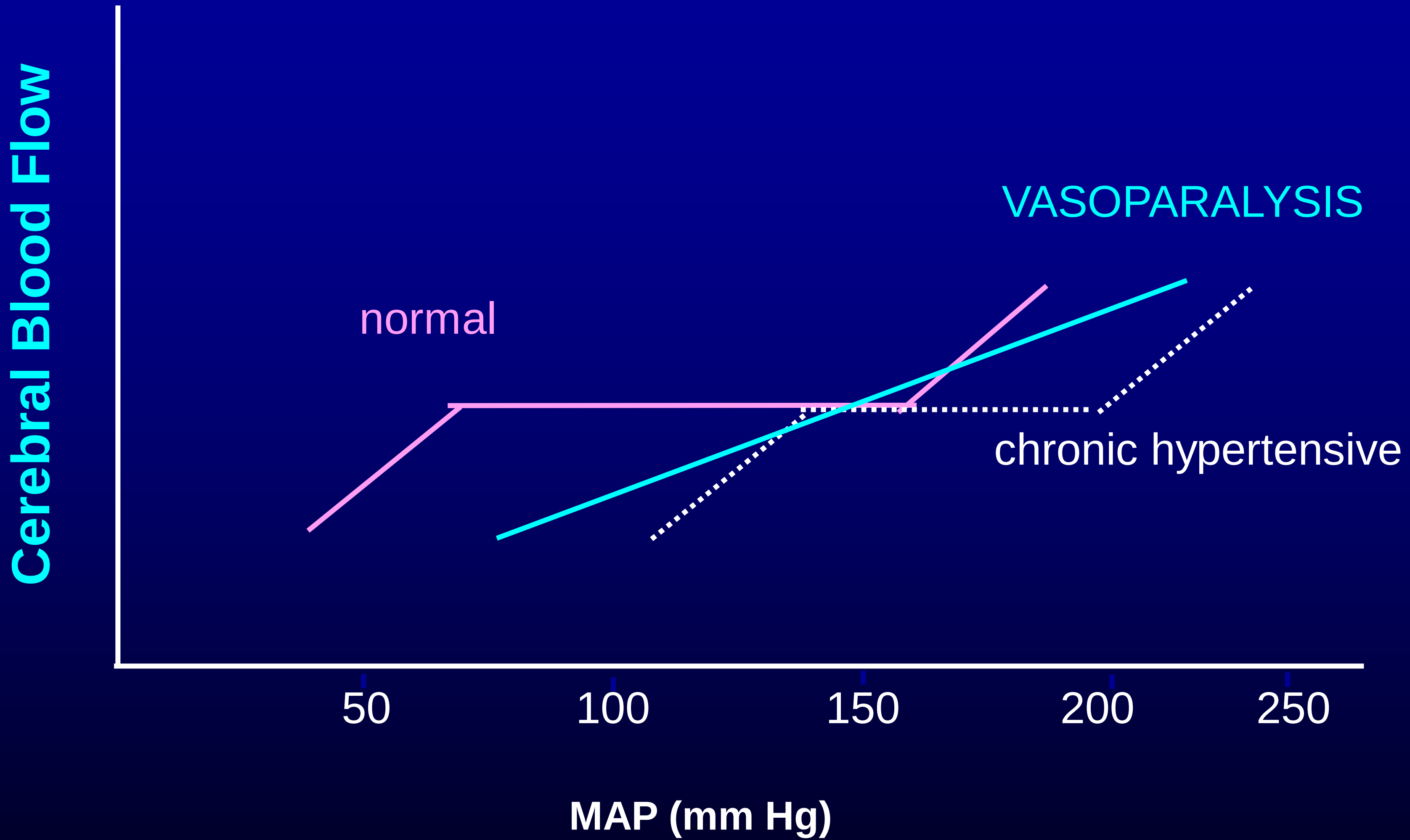
- PbrO2 Levels Integrate Oxygen
  - DELIVERY ← CPP/MAP
  - DIFFUSION ← Osmotherapy
  - CONSUMPTION ← Sedation, Cooling
- Variables that Influence Blood O2 Content
  - FiO2
  - Hemoglobin




PbrO2
mm Hg
54
39
24
9
09 JUL
23:15 23:30 23:45 0:00 0:15 0:30 0:45 1:00
CPP
mm Hg
133
93
53
09 JUL
23:15 23:30 23:45 0:00 0:15 0:30 0:45 1:00
ICP
mm Hg
37
29
21
13
09 JUL
23:15 23:30 23:45 0:00 0:15 0:30 0:45 1:00


Scatterplot of Cerebral Perfusion Pressure by Brain Oxyge
Time Period 900-1000 Minutes
r^2 = 0.6934
pbO2
CPP
36
34
32
30
28
26
24
22
20
30
40
50
60
70
80
90

Cerebral Autoregulation



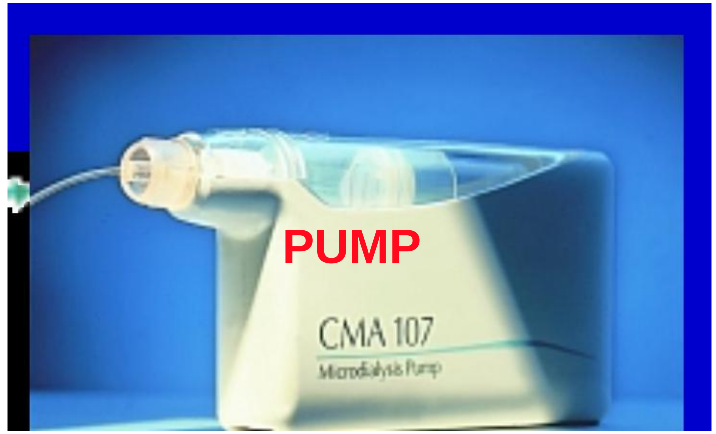
Adapted with permission from Varon J, Marik PE. *Chest.* 2000;118:214-227.

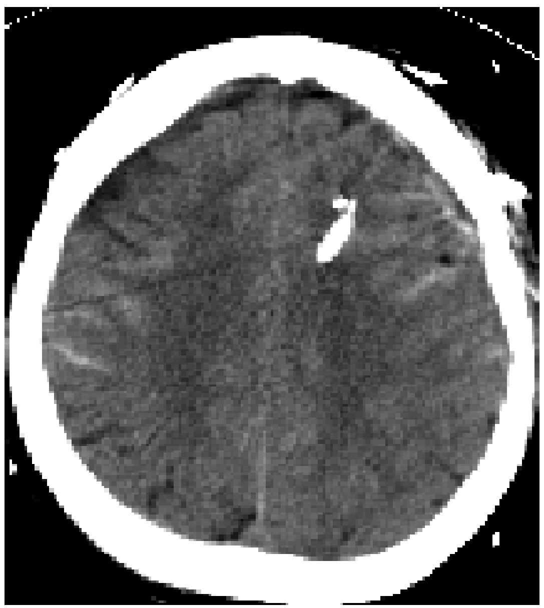
Cerebral Microdialysis

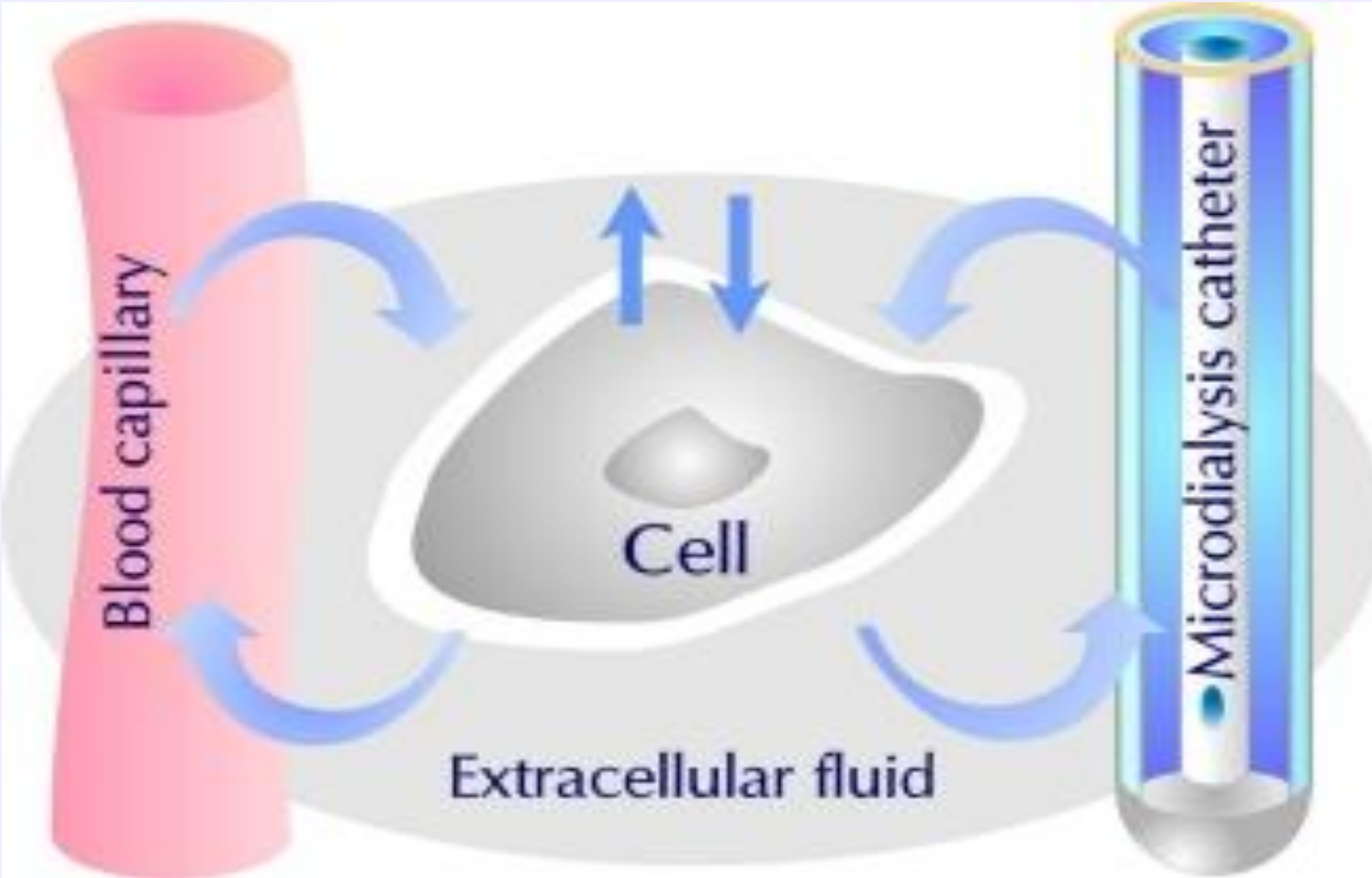
DIALYSATE IN

BRAIN

RECEPTACLE:
Dialysate Out



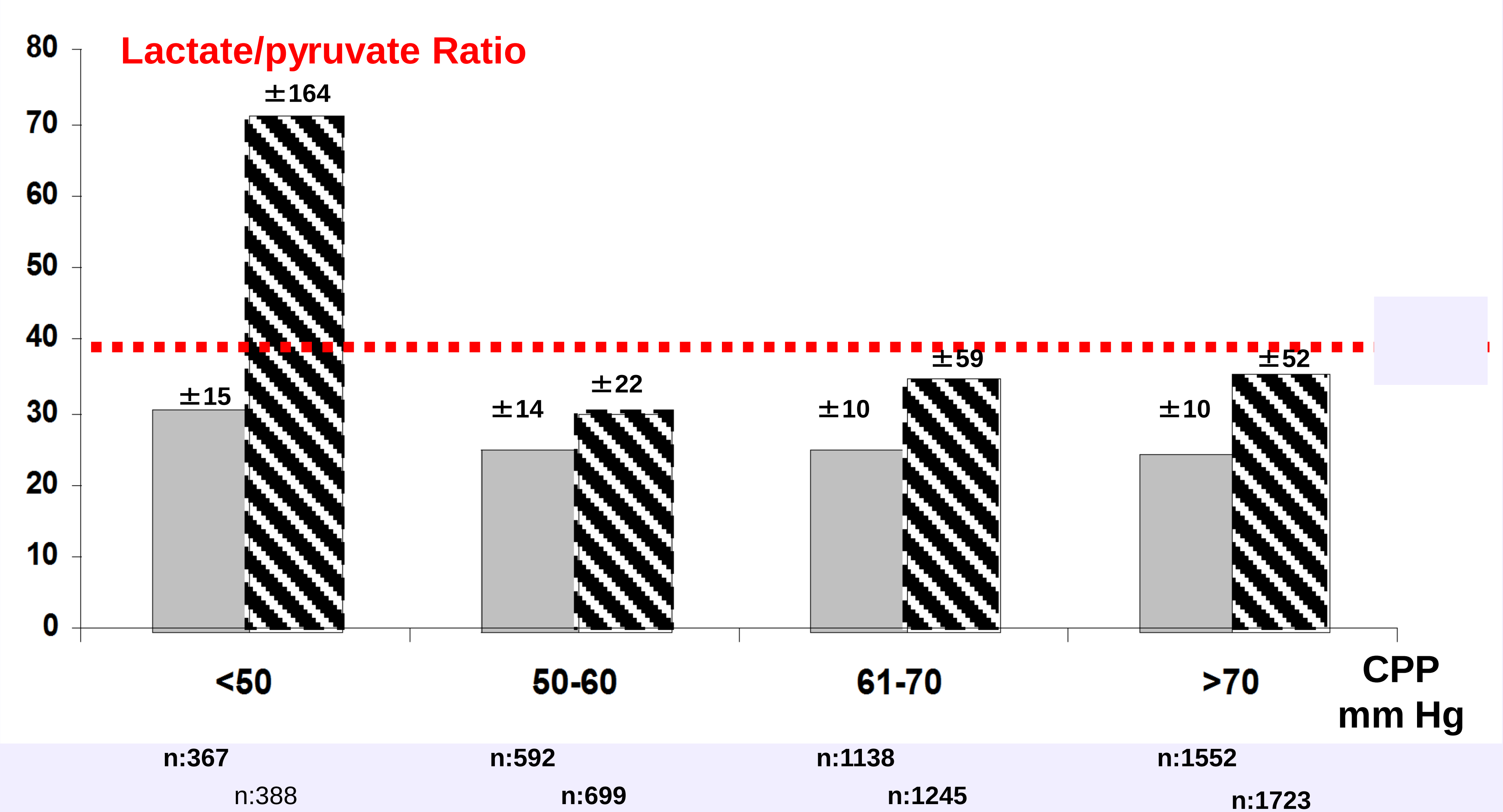



Blood capillary
Cell
Microdialysis catheter
Extracellular fluid

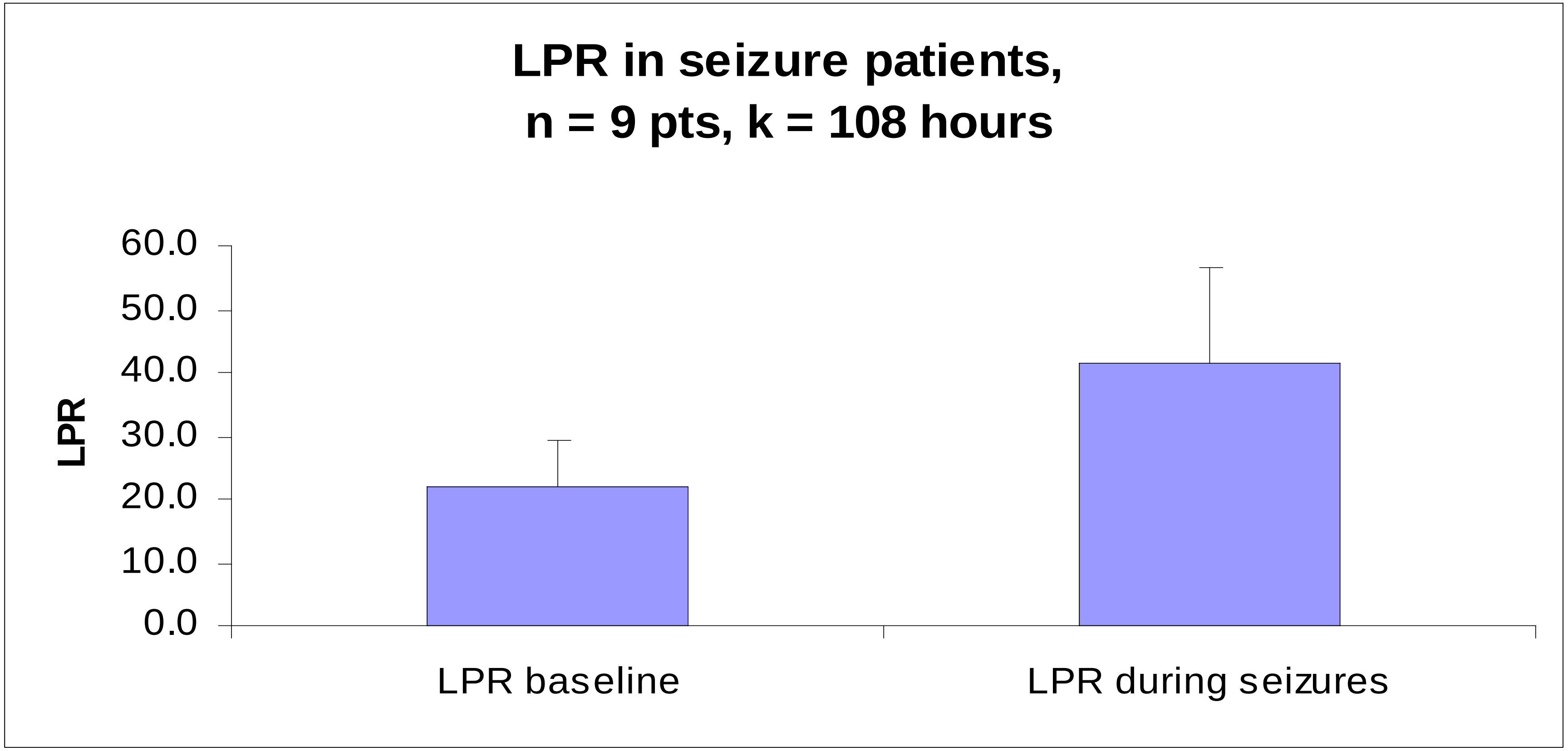
MICRODIALYSIS

- 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



Increase in extracellular LPR with nonconvulsive seizures



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

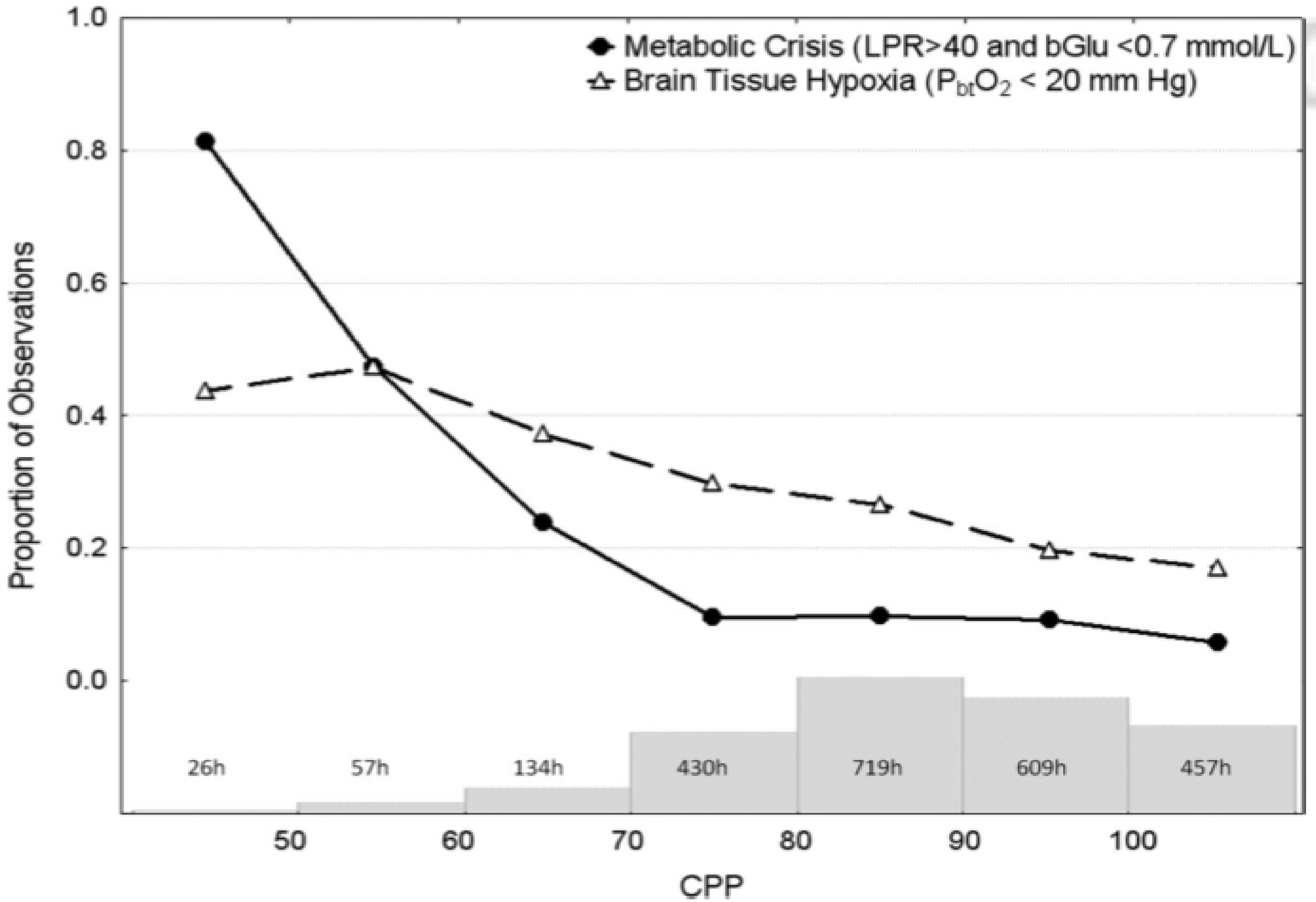
N = 140

PbtO2 often passively varies with fluctuations in CPP and can serve as an endpoint for **goal-directed therapy**

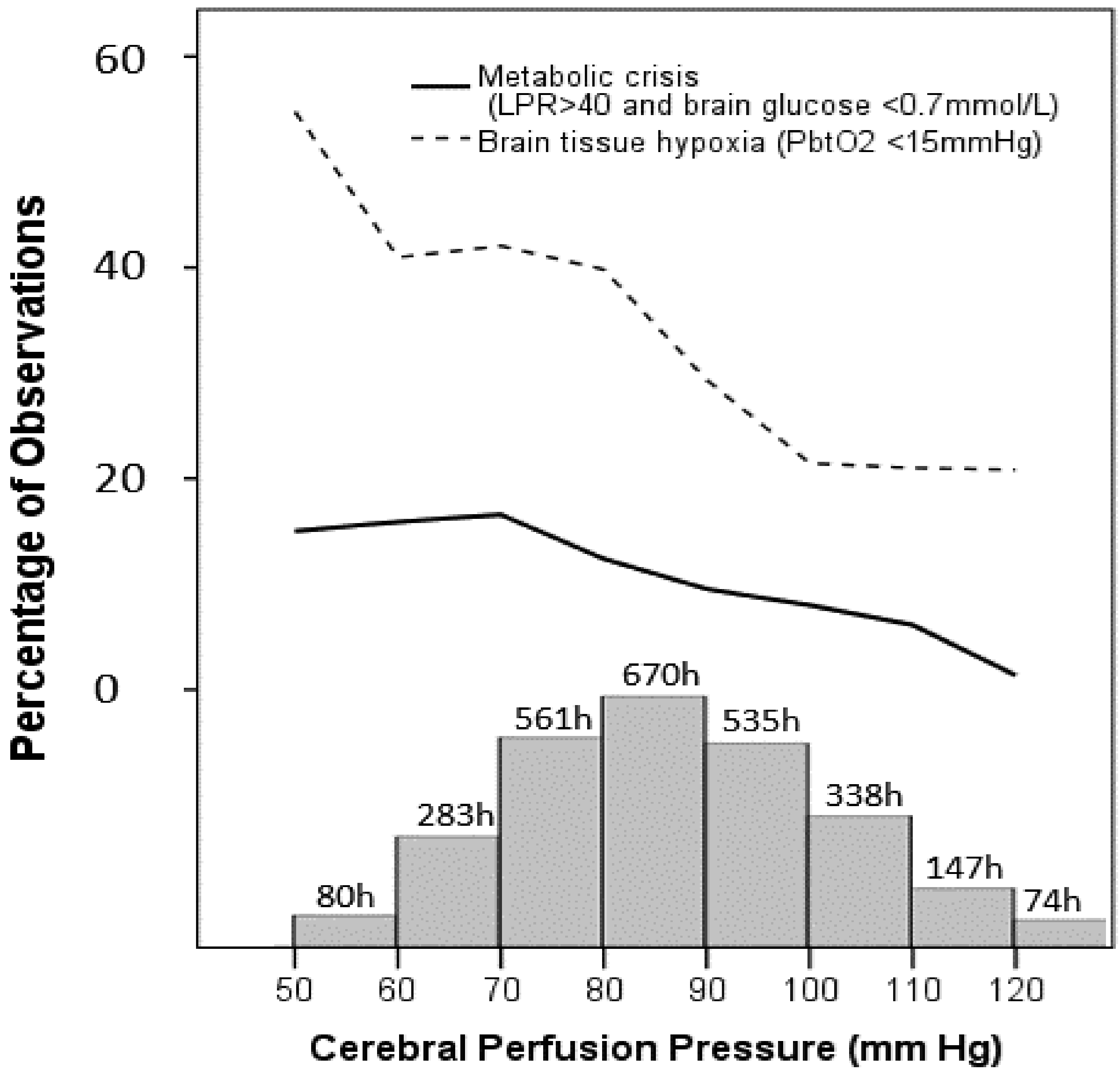
Ko S-B, et al: **Multimodality Monitoring for Cerebral Perfusion Pressure Optimization in Comatose Patients with Intracerebral Hemorrhage *Stroke* 2011**

Schmidt JM. Et al: Blood pressure thresholds for brain tissue hypoxia and metabolic crisis after poor-grade subarachnoid hemorrhage. *Stroke* 2011

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

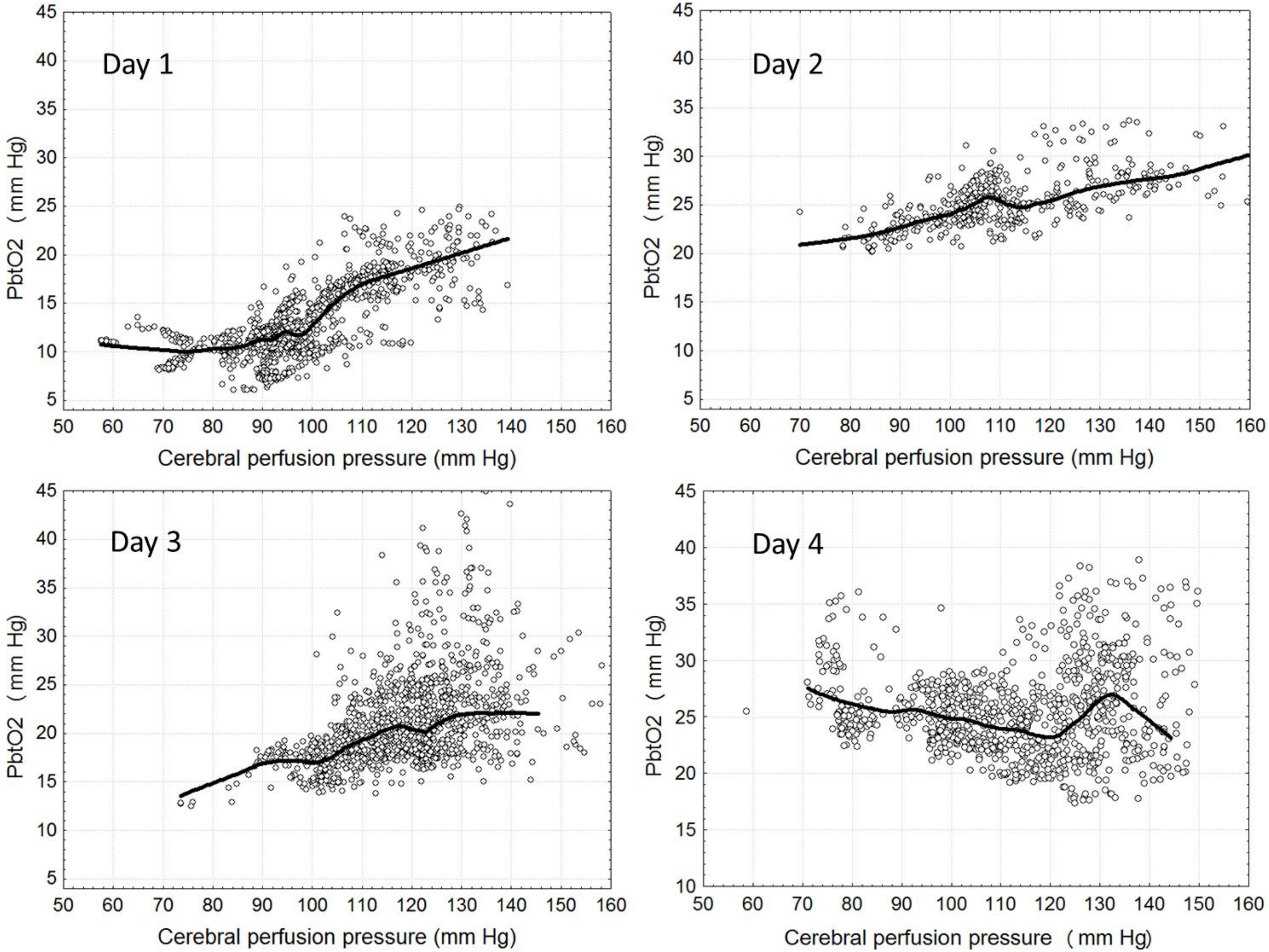


Schmidt JM. Et al: Blood pressure thresholds for brain tissue hypoxia and metabolic crisis after poor-grade subarachnoid hemorrhage. ***Stroke*** **2011**



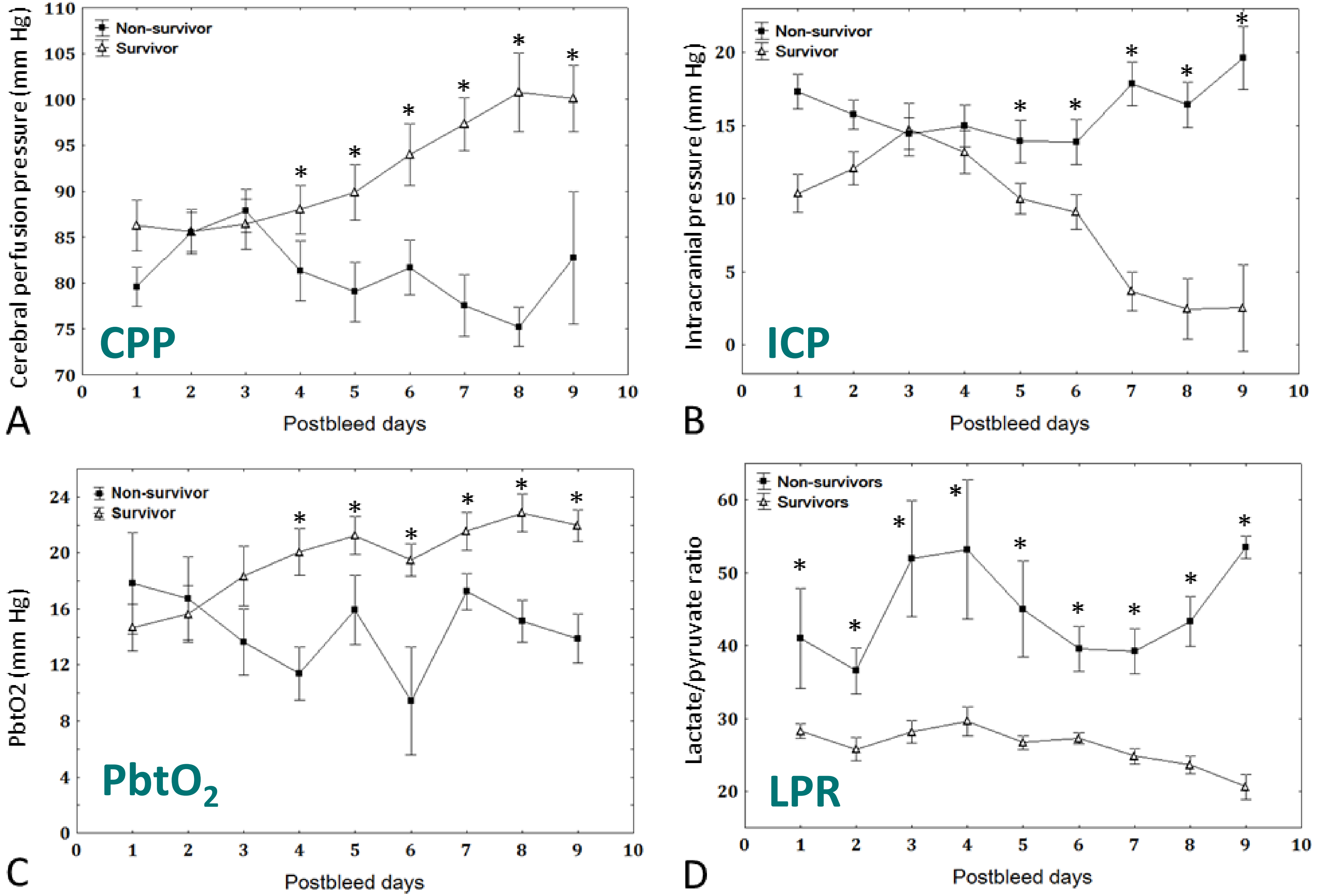
Brain Tissue Hypoxia and Metabolic Crisis Increase with Lower CPP in Comatose Patients with ICH

Ko S-B, et al: **Multimodality Monitoring for Cerebral Perfusion Pressure Optimization in Comatose Patients with Intracerebral Hemorrhage *Stroke* 2011**



IMAGING AUTOREGULATORY FAILURE AND ITS NORMALIZATION

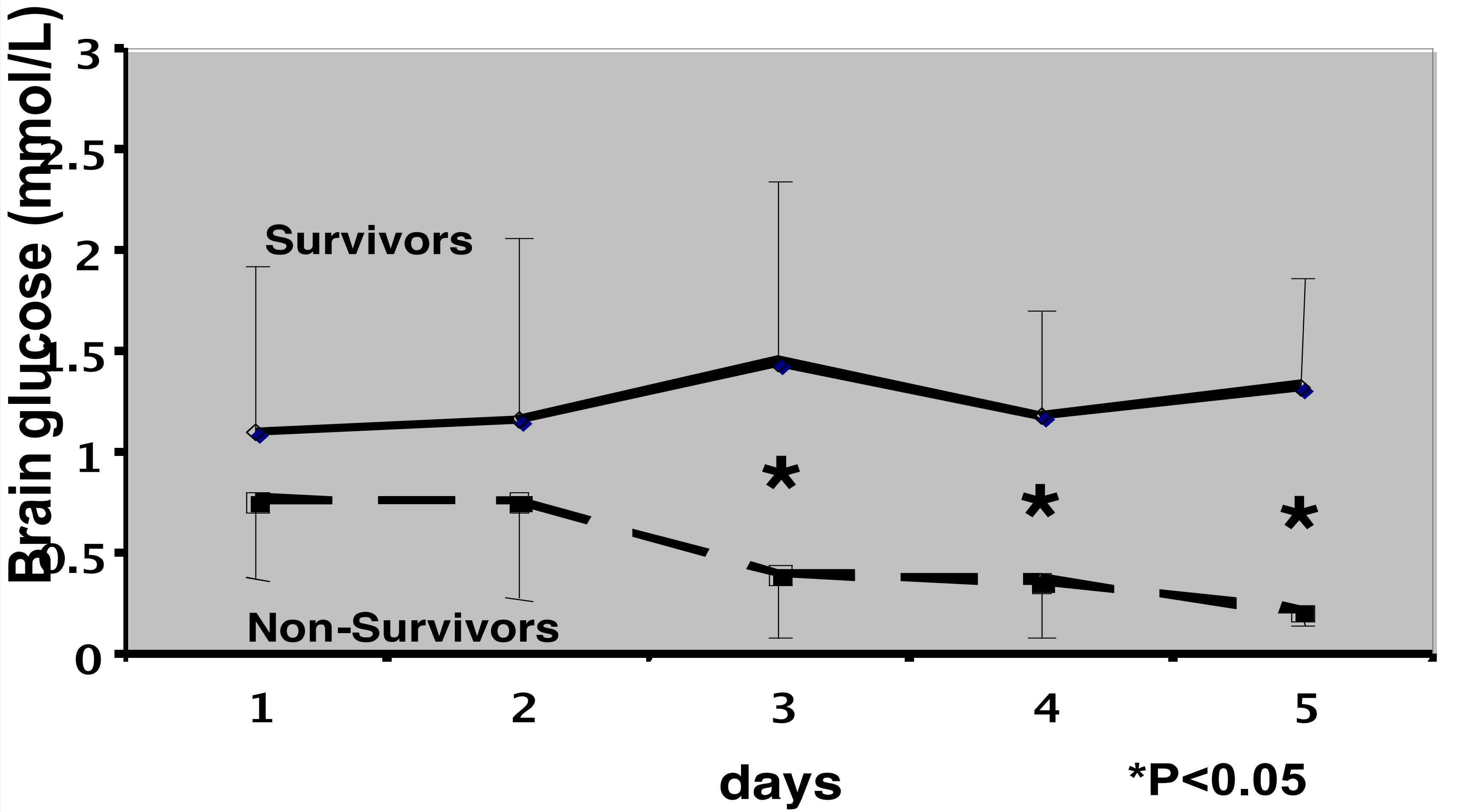
Comatose ICH Survivors: Lower ICP & LPR, Higher CPP & PbtO2



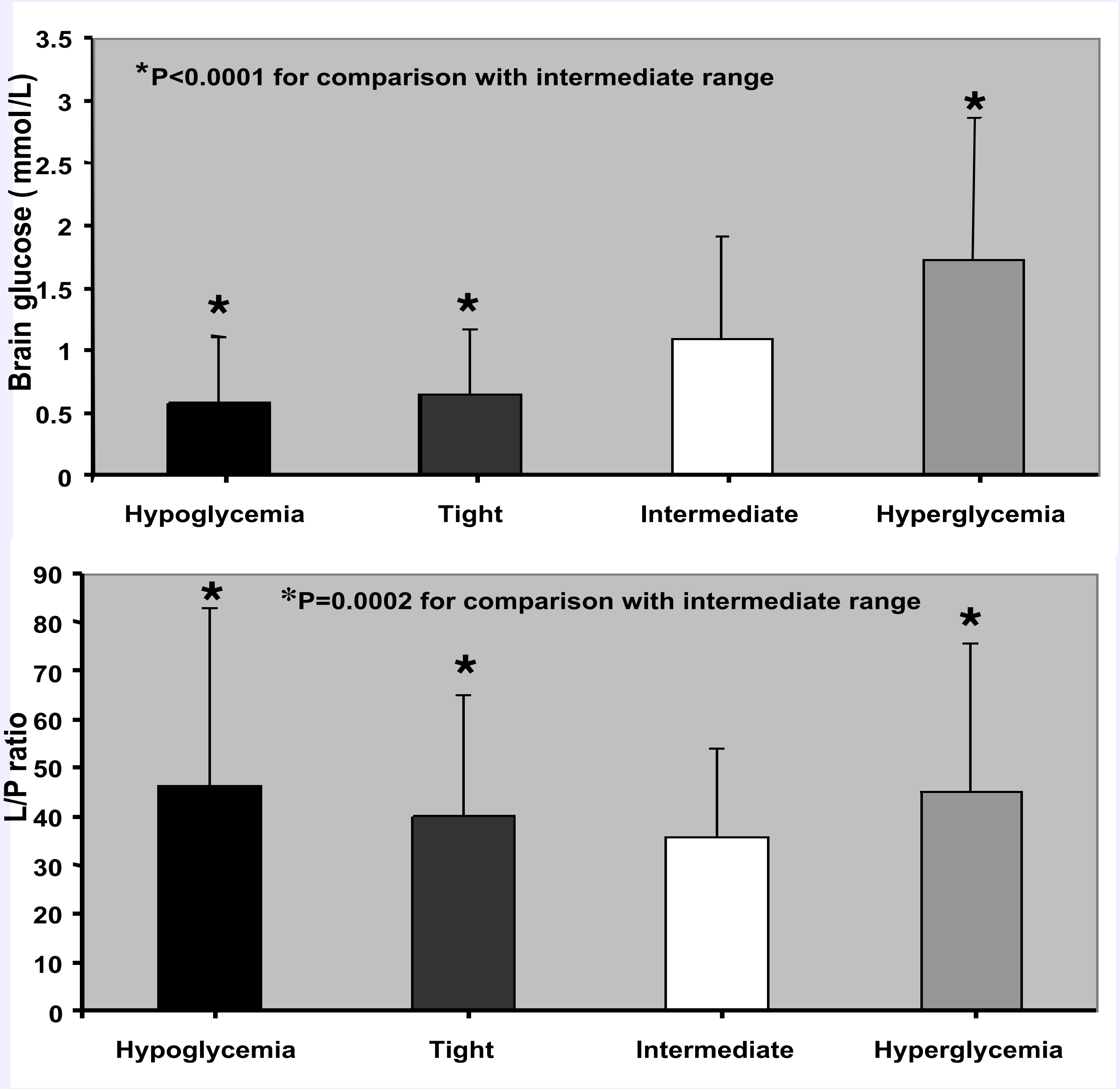
The “best practice” of intensive insulin infusion for tight glycemic control in brain injured patients is associated with

critical brain hypoglycemia

Oddo M, et al: **Impact of insulin therapy on brain glucose levels after severe brain injury: a microdialysis study.** *Crit Care Med* 2008;36:3233-3238.

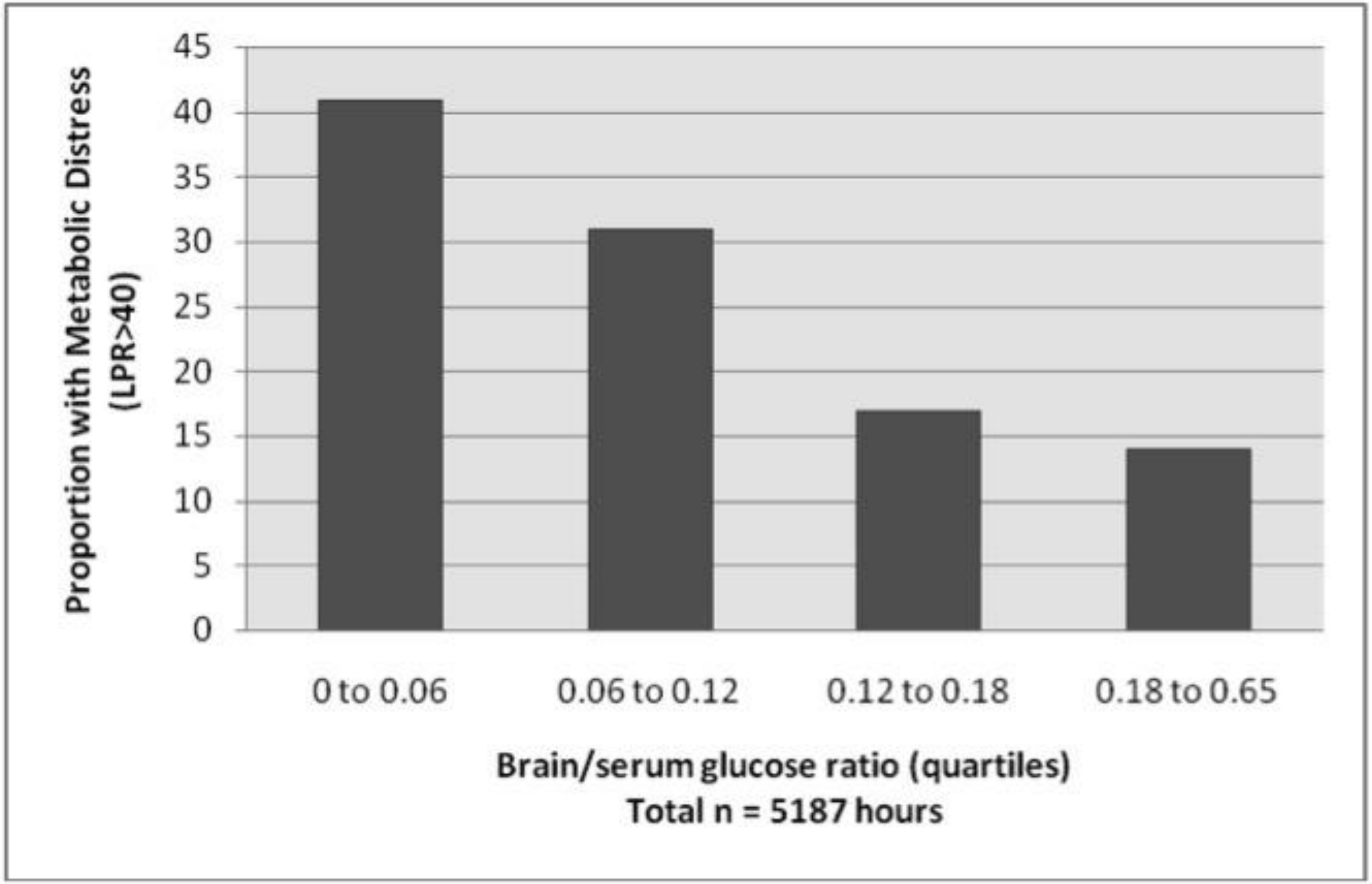


Brain glucose (mmol/L)
3
2.5
2
1.5
1
0.5
0
Survivors
Non-Survivors
*
*
*
1
2
3
4
5
days
*P<0.05



*P<0.0001 for comparison with intermediate range
Brain glucose (mmol/L)
3.5
3
2.5
2
1.5
1
0.5
0
*
*
*
Hypoglycemia
Tight
Intermediate
Hyperglycemia
*P=0.0002 for comparison with intermediate range
L/P ratio
90
80
70
60
50
40
30
20
10
0
*
*
*
Hypoglycemia
Tight
Intermediate
Hyperglycemia

Figure 1.

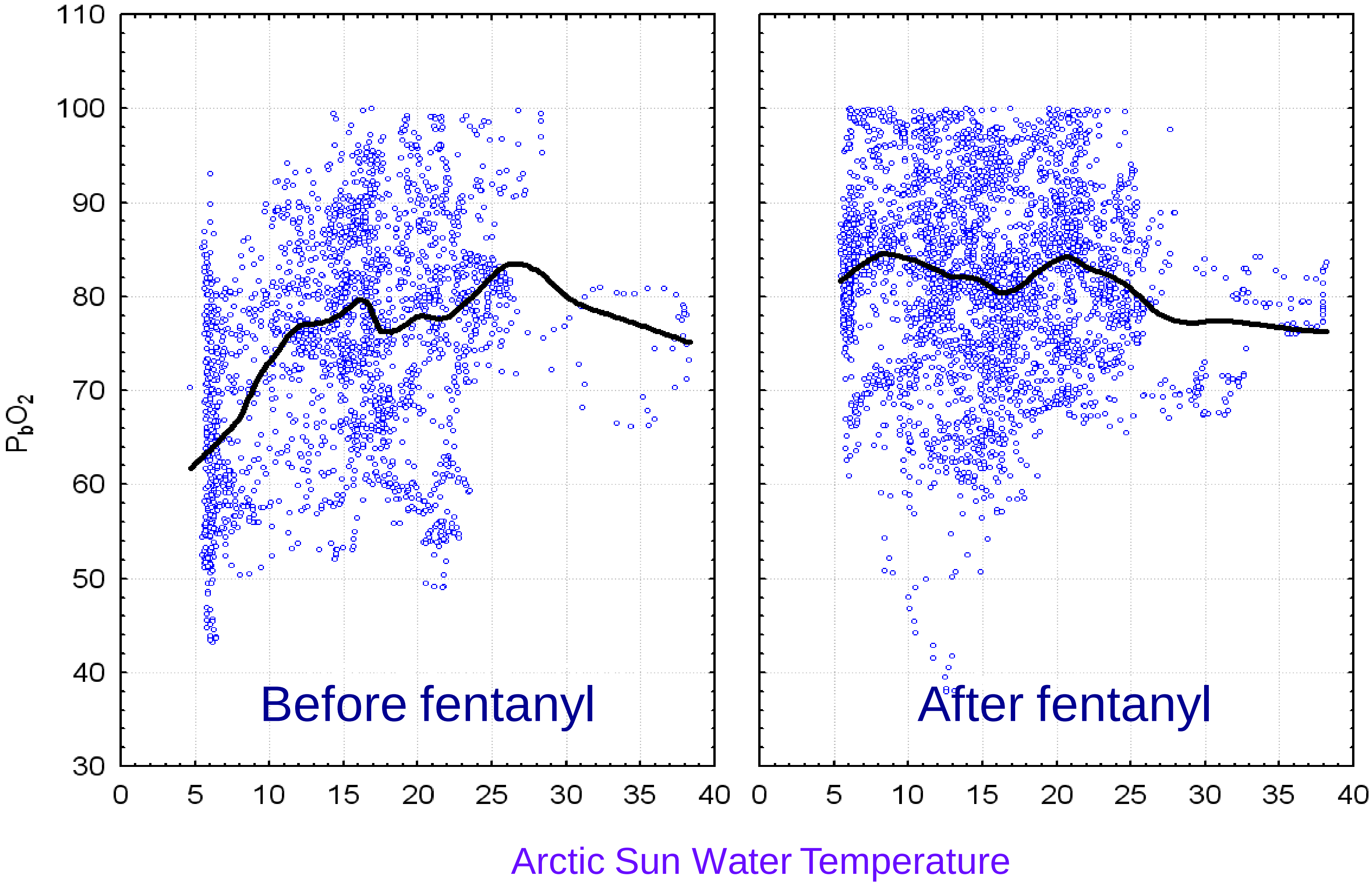


Kurtz, et al: **Reduced Brain/Serum Glucose Ratios Predict Metabolic Distress and Mortality after Severe Brain Injury**. Int Care Med (submitted)

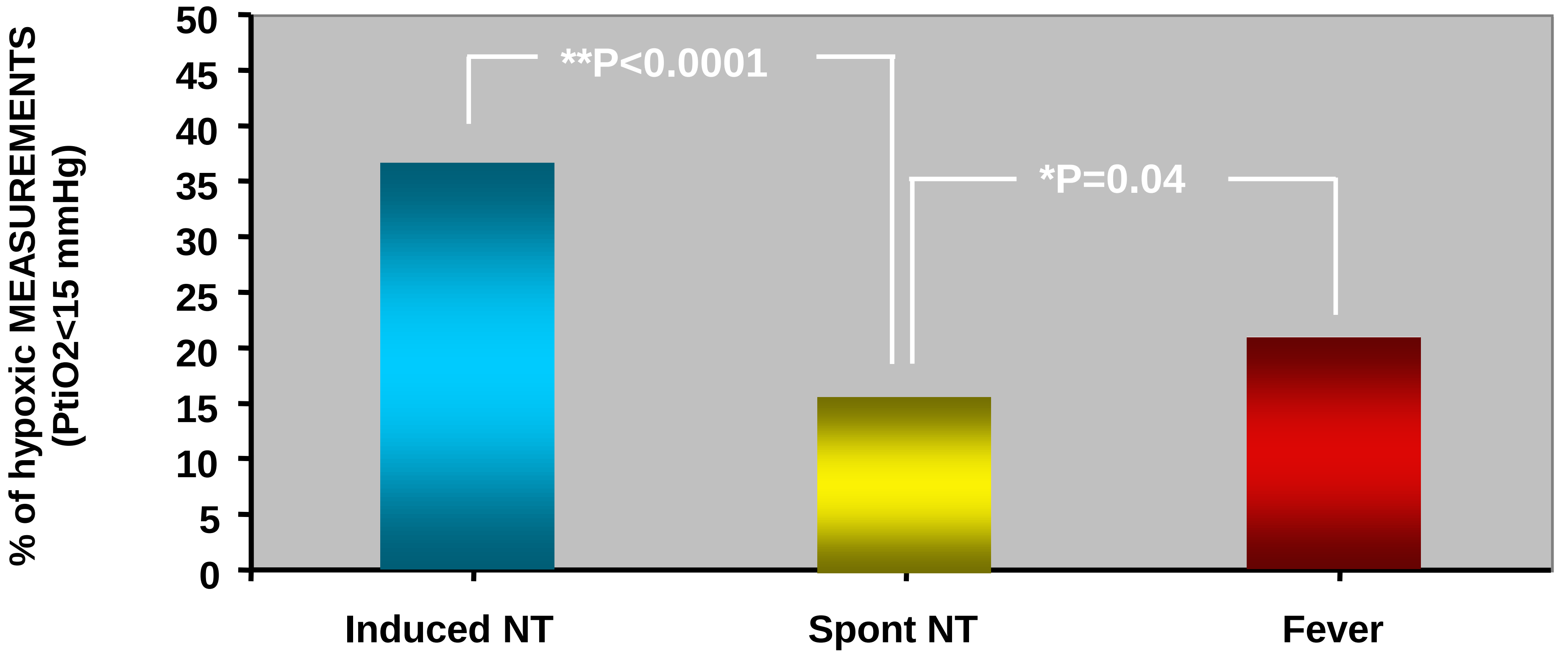
Fever reduces brain tissue oxygen levels – but cooling with inadequate control of shivering makes the brain hypoxia even **worse!**

Oddo M, Badjatia N et al. **Effect of induced cooling on brain tissue oxygenation after severe brain injury** (in preparation)

Impact of Shiver control on brain oxygenation



Brain hypoxia is increased with induced normothermia



Oddo M, et al, **Effect of induced normothermia on brain tissue oxygenation after subarachnoid hemorrhage** (in preparation)

Columbia Anti-Shivering Protocol

neurocritical care society Neurocrit Care
DOI 10.1007/s12028-010-9474-7

ORIGINAL ARTICLE

Prevention of Shivering During Therapeutic Temperature Modulation: The Columbia Anti-Shivering Protocol

H. Alex Choi · Sang-Bae Ko · Mary Presciutti · Luis Fernandez · Amanda M. Carpenter · Christine Lesch · Emily Gilmore · Rishi Malhotra · Stephan A. Mayer · Kiwon Lee · Jan Claassen · J. Michael Schmidt · Neeraj Badjatia

Emphasizes skin counterwarming and magnesium→ dexmedetomidine → conventional analgosedation

Severe unintentional

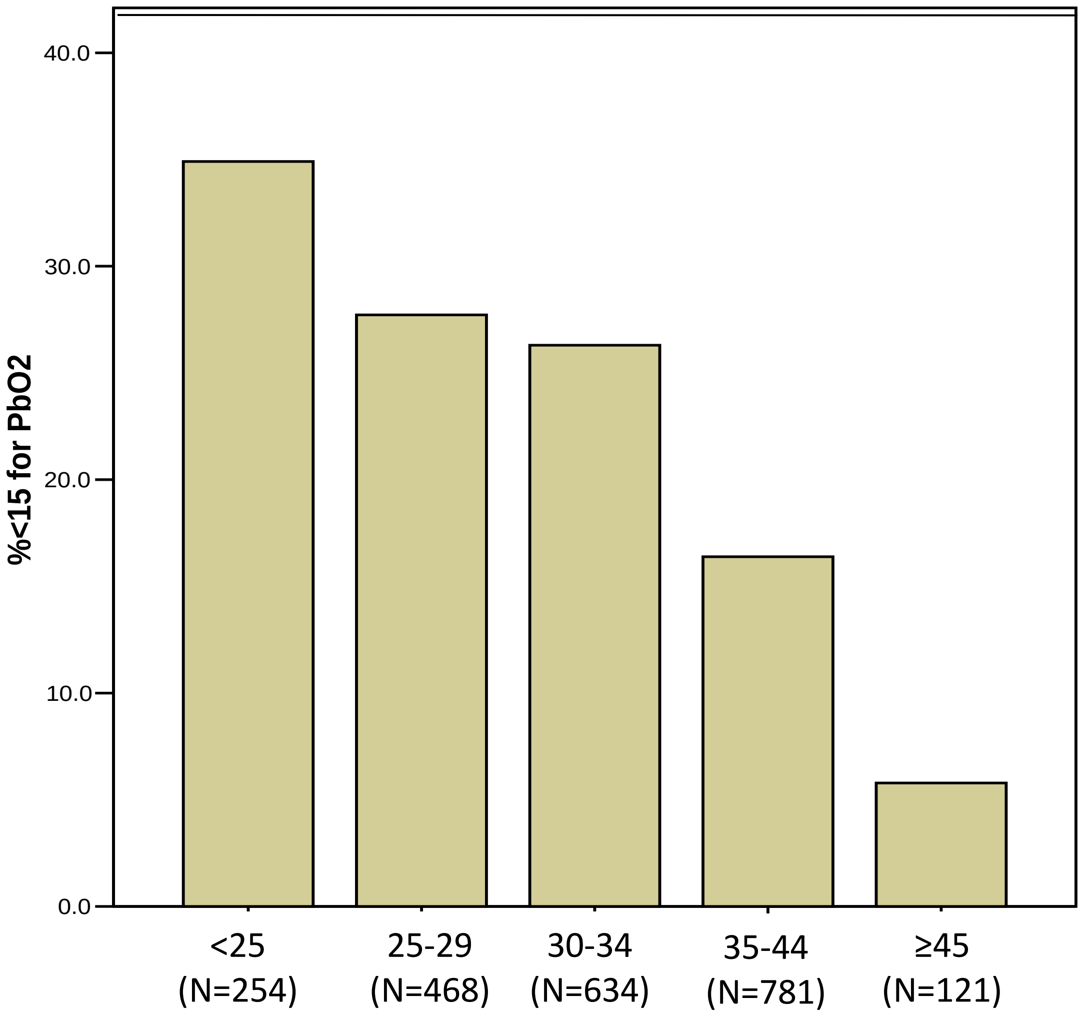
central hyperventilation

is a common and unrecognized of

critical brain tissue hypoxia

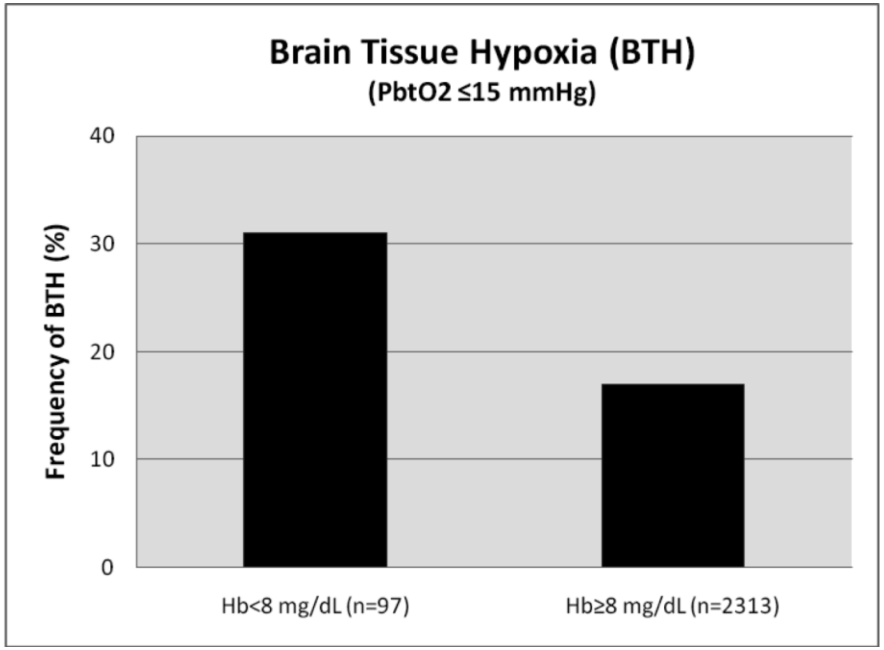
Carrerra E: **Hyperventilation and Brain Tissue Hypoxia in Patients with Severe Brain Injury.** JNNP 2011

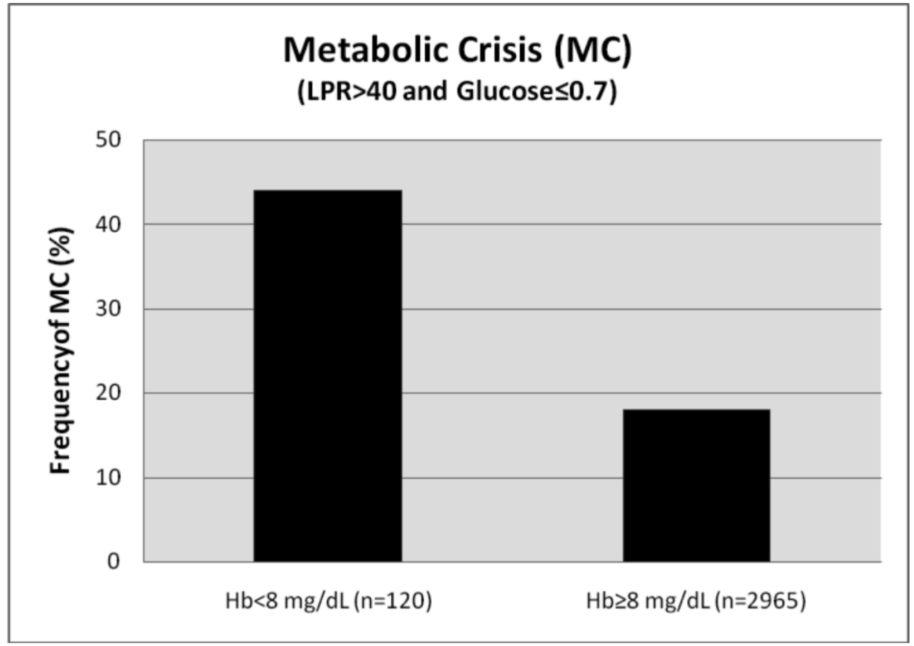
Frequency of Brain Tissue Hypoxia (PbtO2 < 15 mmHg) Related to Concurrent $EtCO_2$



Mild levels of **anemia** considered acceptable in MICU patients are associated with reduced brain tissue oxygen levels in neurological patients

Kurtz P, et al: **Anemia is associated with brain tissue hypoxia and metabolic crisis after severe brain injury.** *Crit Care Med* (in preparation)





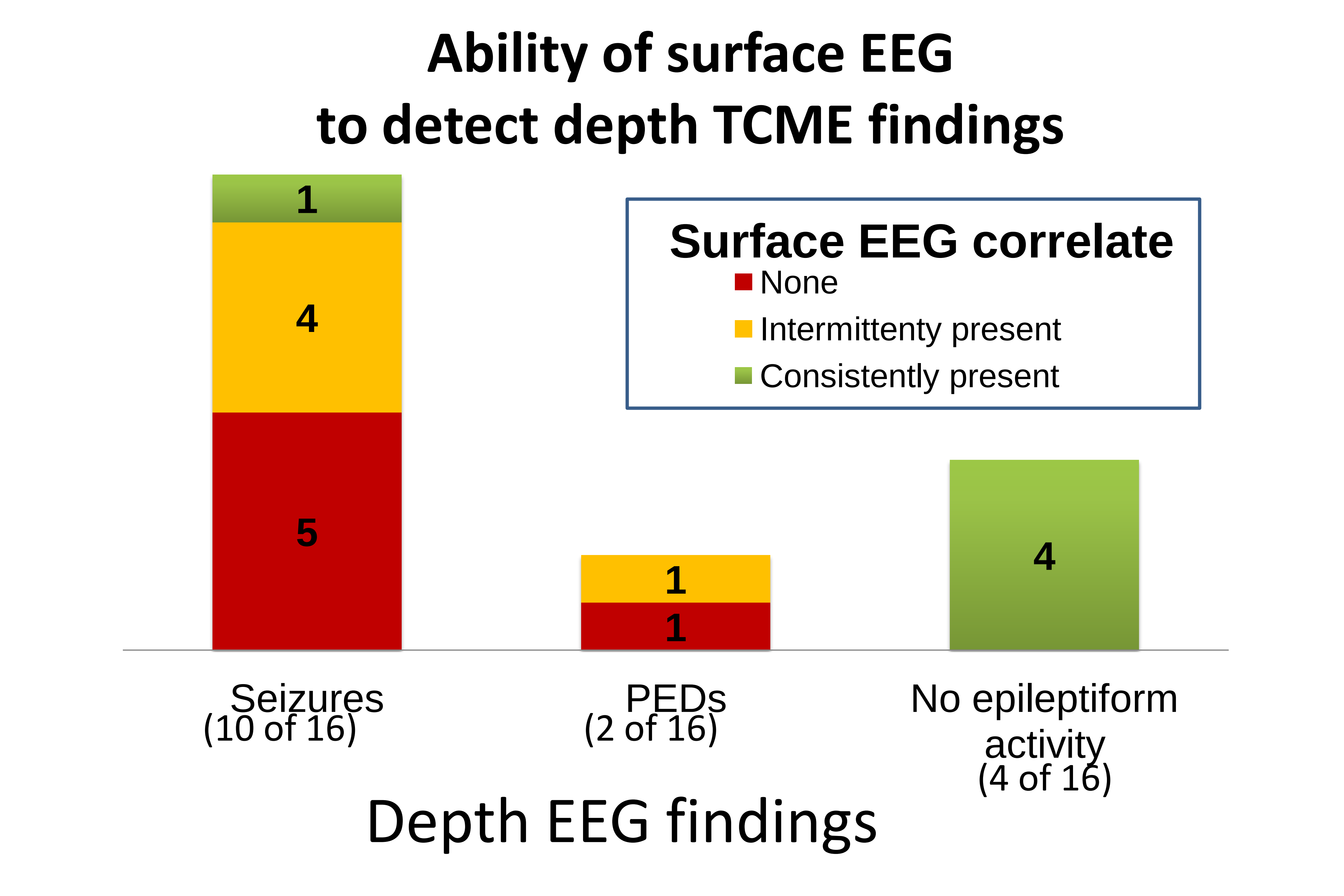
Brain Tissue Hypoxia and Metabolic Crisis is Associated With Hb Levels <8.0 mg/dl

Insertion of an EEG depth electrode in comatose patients reveals previously **"hidden" seizure activity** in one-third of patients

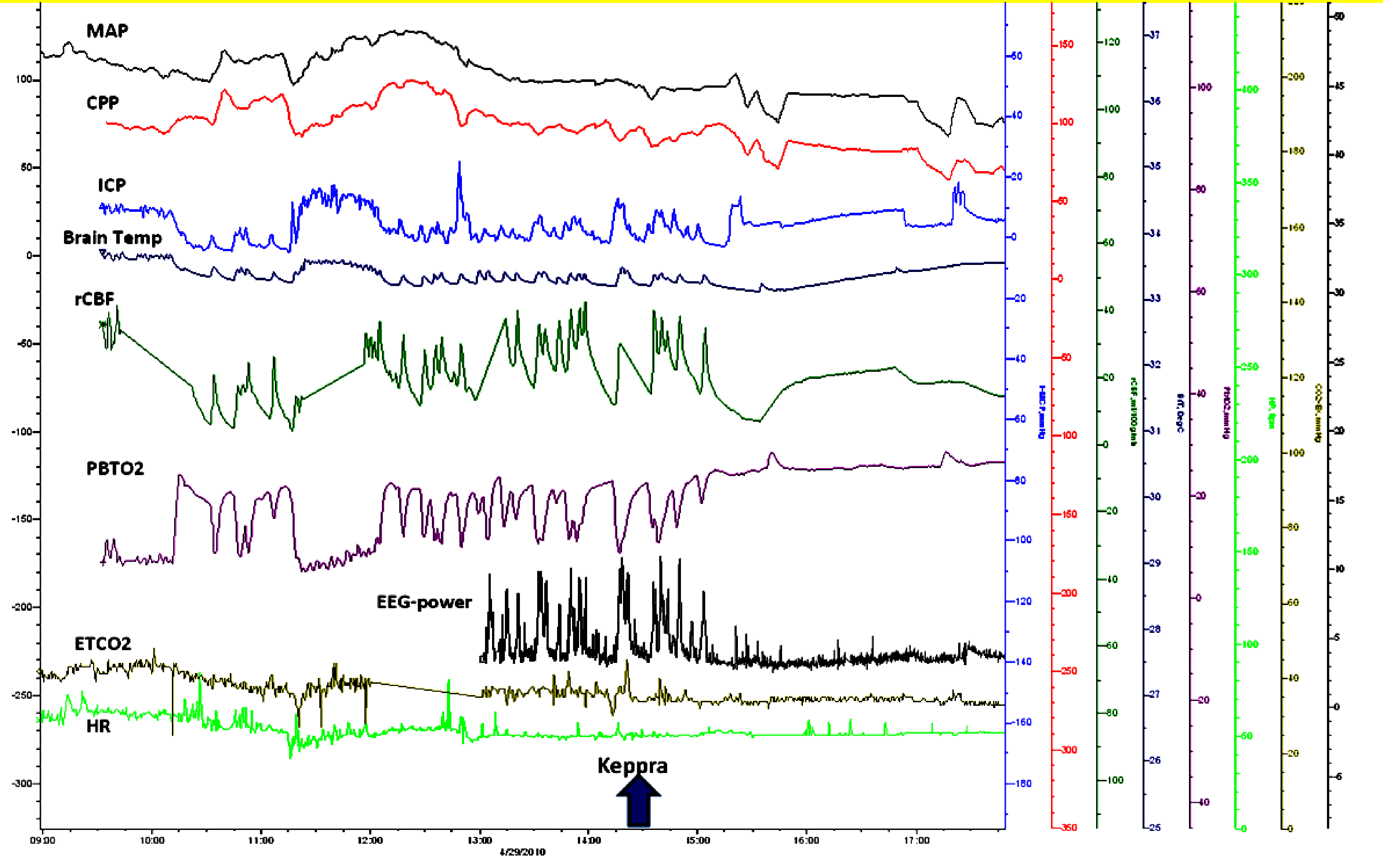
Waziri A, et al: **Intracortical electroencephalography in acute brain injury.** *Ann Neurol* 2010

Seizures on the depth without scalp correlate

74 yo woman with SAH (HH grade III)

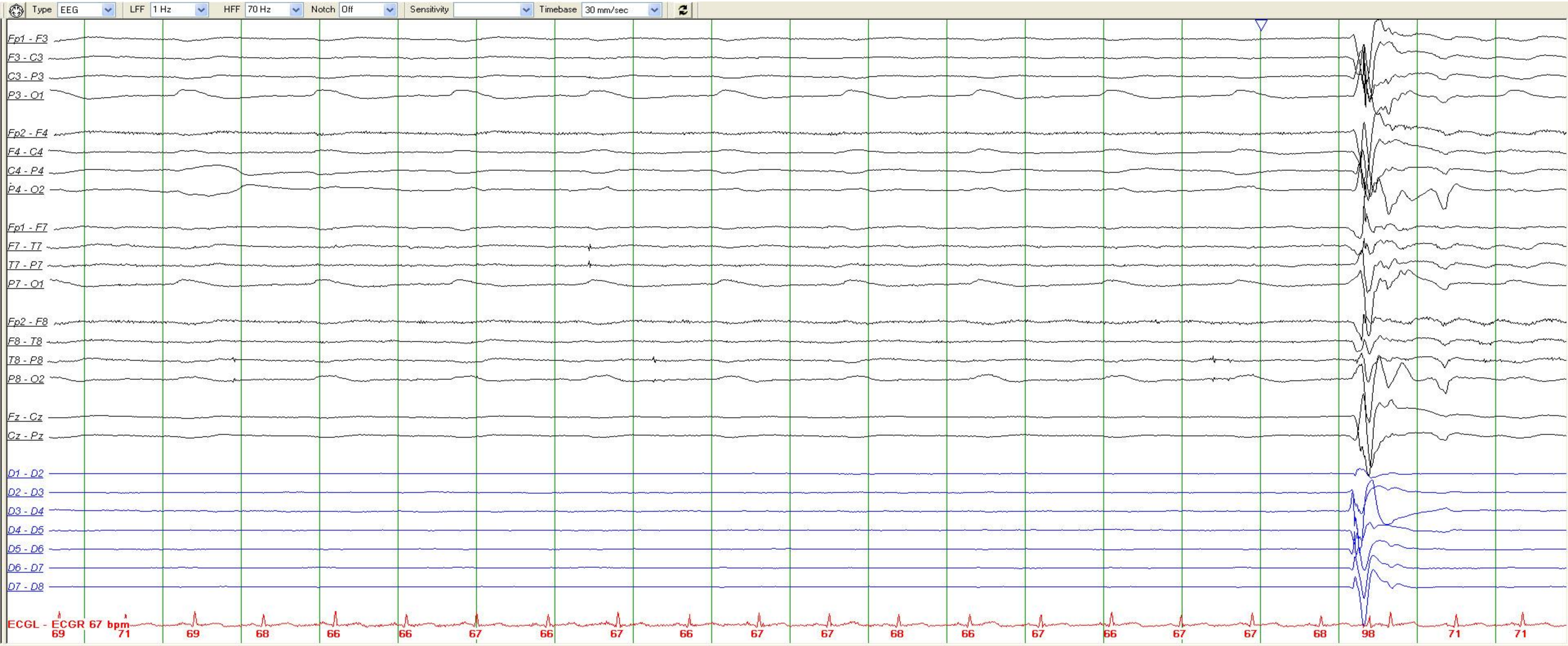

Ability of surface EEG
to detect depth TCME findings
Surface EEG correlate
None
Intermittenty present
Consistently present
1
4
5
1
1
4
Seizures
(10 of 16)
PEDs
(2 of 16)
No epileptiform activity
(4 of 16)
Depth EEG findings

80 year-old man s/p PEA arrest GCS-3 with bilateral eye twitching



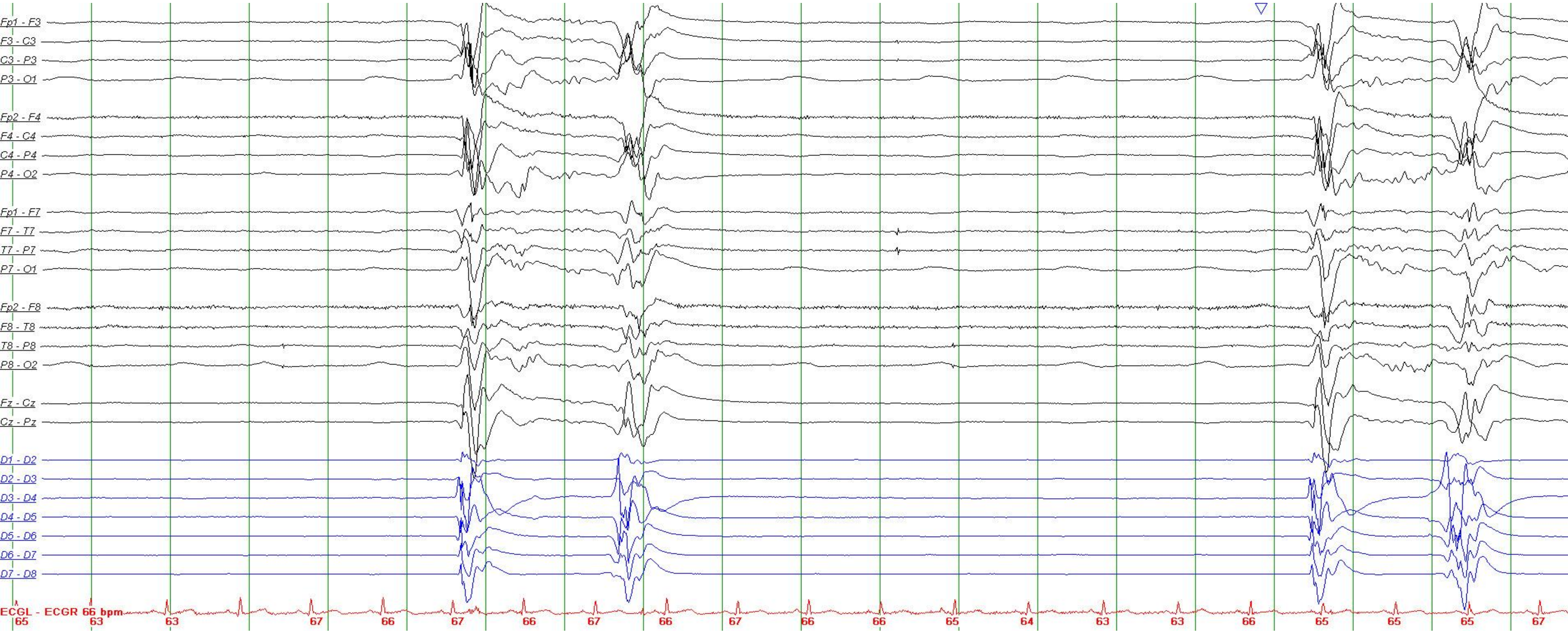
27 year old man with asthma leading to respiratory failure and cardiac arrest

EEG



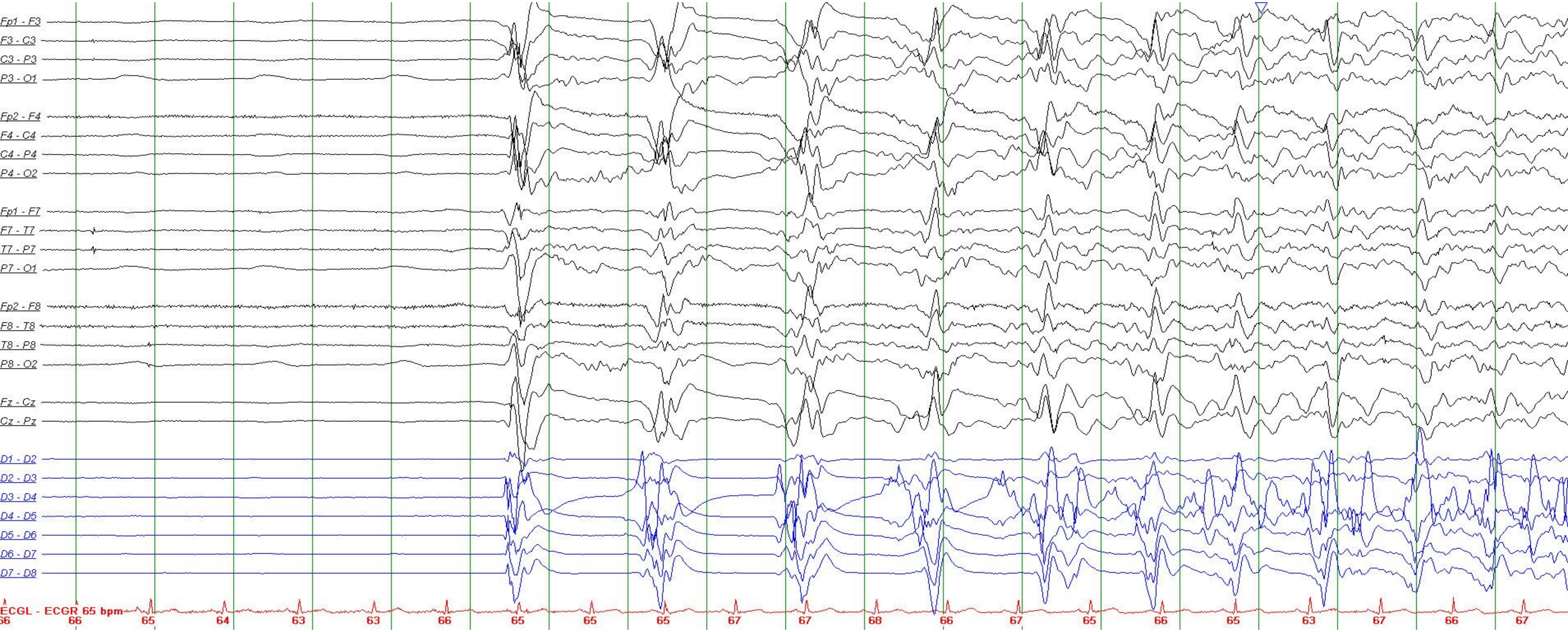
Initially, the background demonstrates diffuse suppression punctuated by generalized bursts corresponding clinically to myoclonus. Scalp electrodes are seen on top (sensitivity 7 μV/mm) and right frontal depth electrodes are seen in blue beneath (D1-D8; sensitivity 15 μV/mm). EKG is seen in red at the bottom (sensitivity 50 μV/mm). Depth electrodes D1 and D2 are likely in subcortical tissue.

EEG



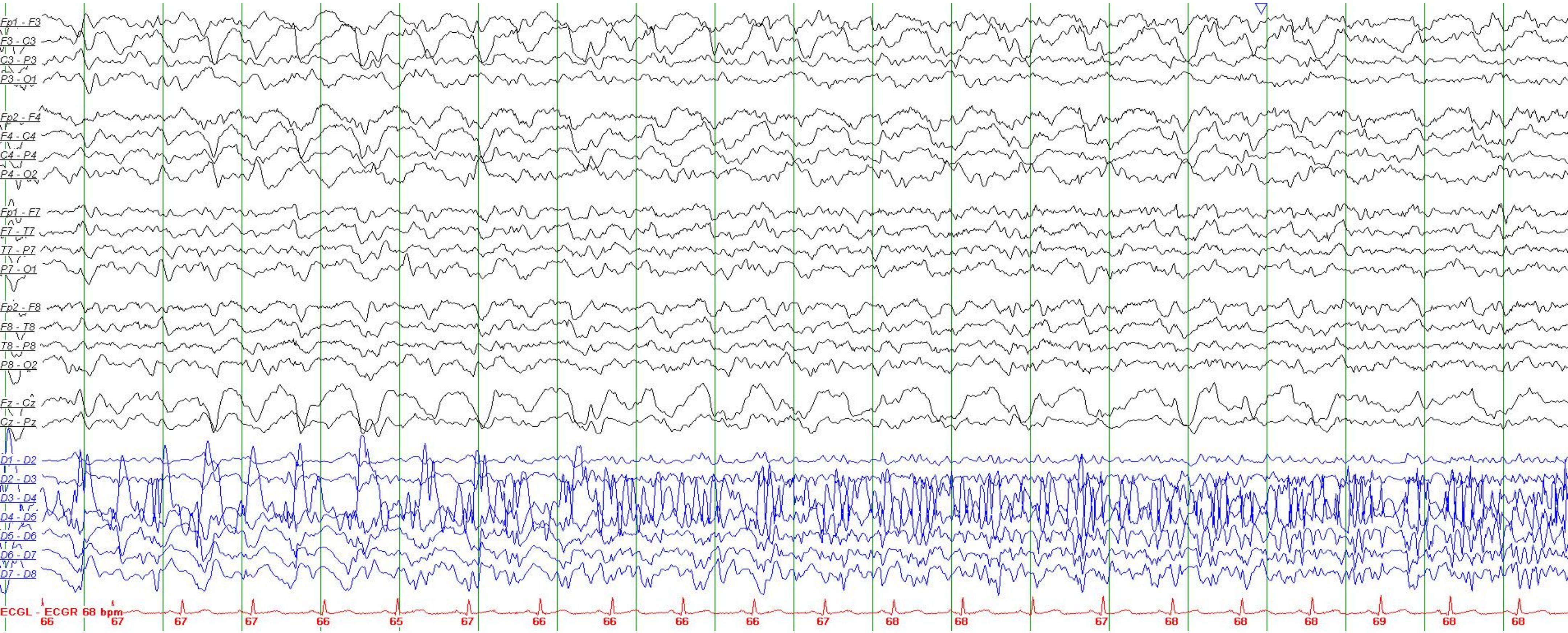
Generalized myoclonic bursts occur in clusters both on scalp and in the depth electrodes.

EEG



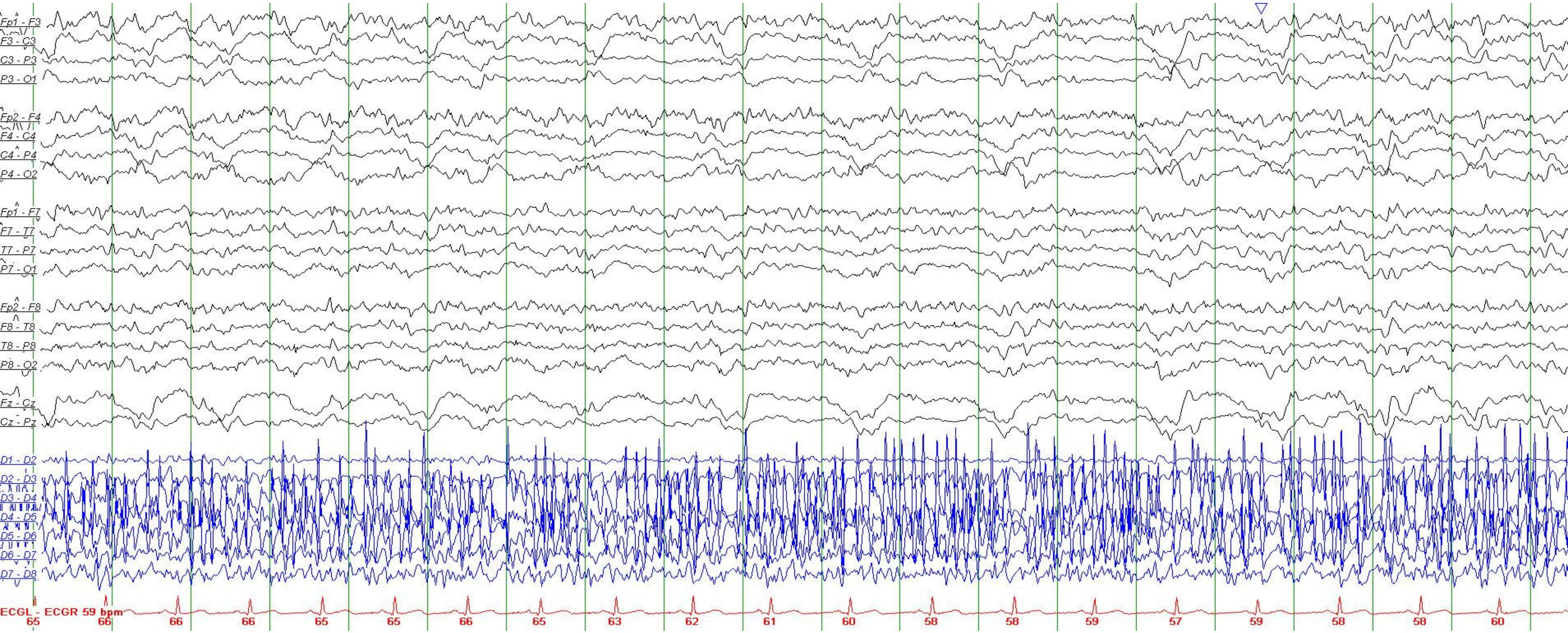
Initially a repetitive run of myoclonus (myoclonic seizure), depth displays underlying rhythmic faster frequencies at D4 between seconds 12 and 14 of this EEG.

EEG



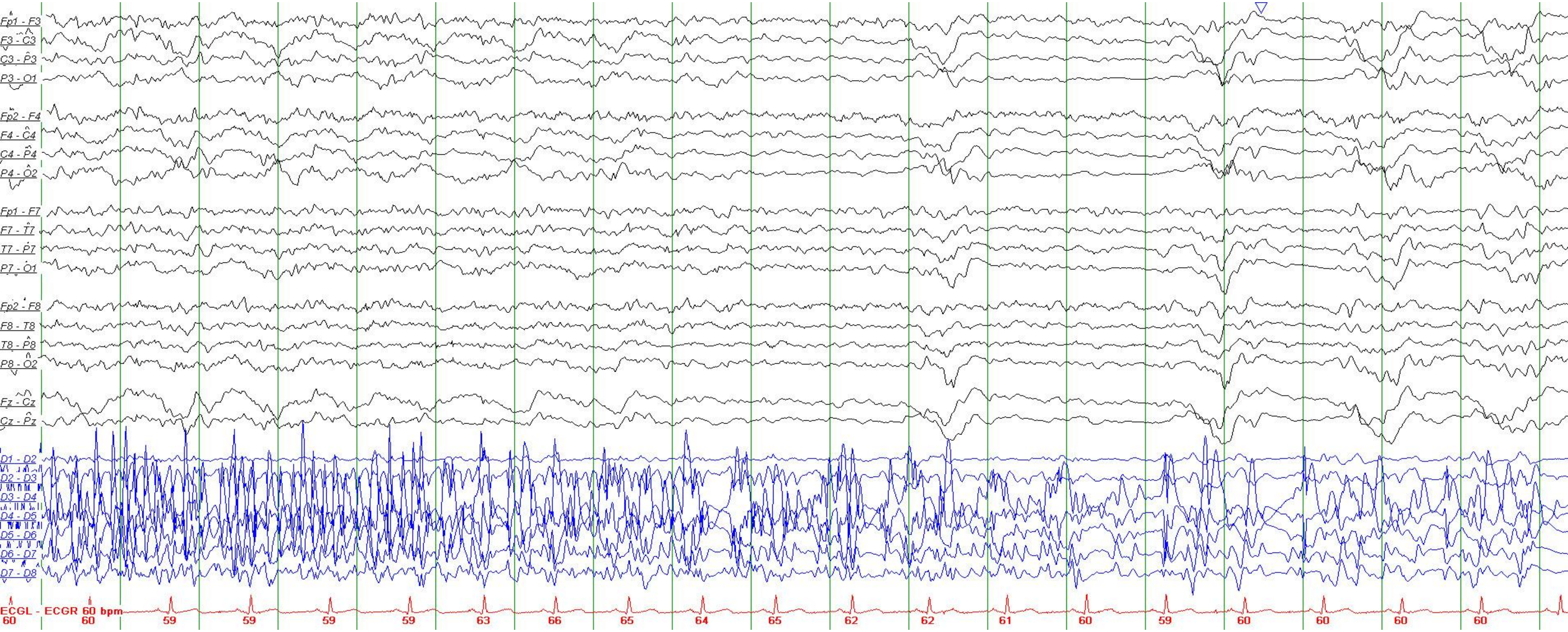
As the myoclonus stops, the depth demonstrates an evolving seizure pattern with rhythmic 8Hz theta-alpha spreading into adjacent electrodes (D5, D6). The scalp demonstrates a frontally-predominant rhythmic delta activity initially at 2Hz evolving to a less defined 1Hz before becoming polymorphic.

EEG

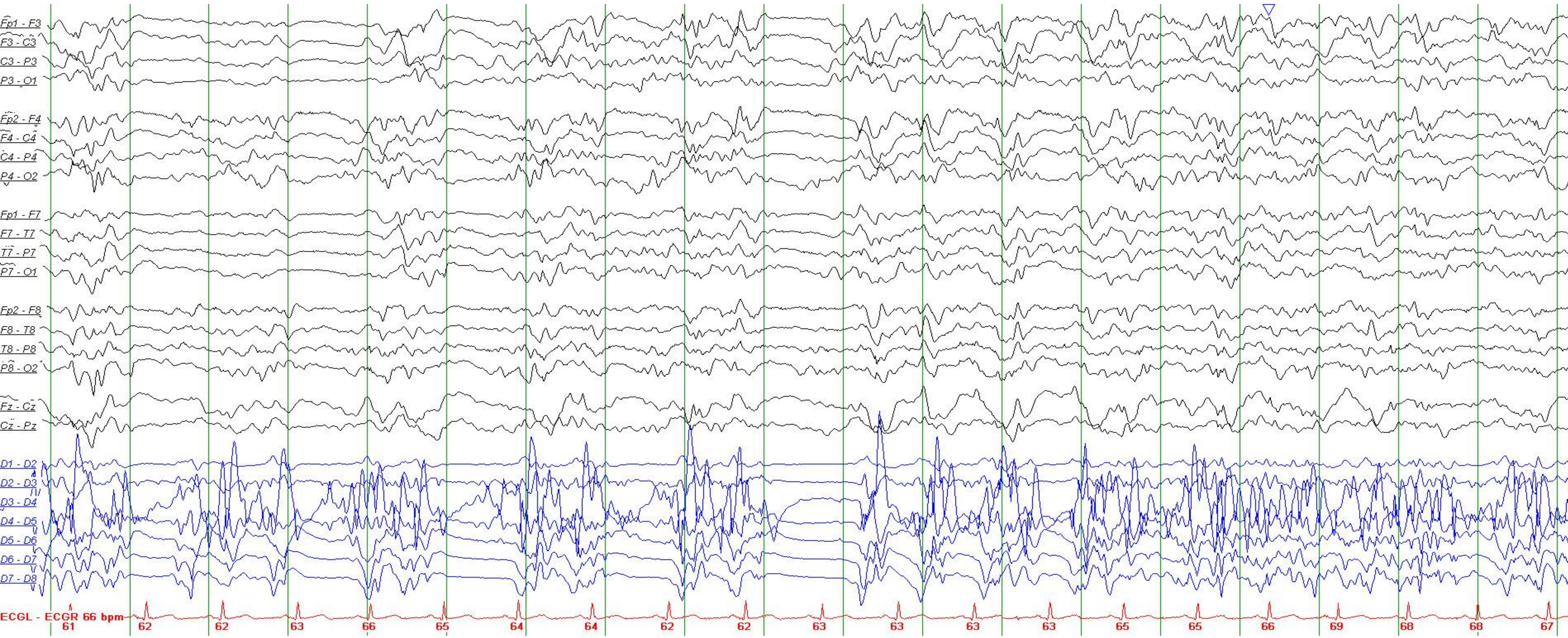


Depth seizure continues to evolve in amplitude and location, now involving all cortically-based electrodes. The scalp demonstrates quasi-rhythmic 0.5Hz delta but primarily non-rhythmic theta frequencies.

EEG

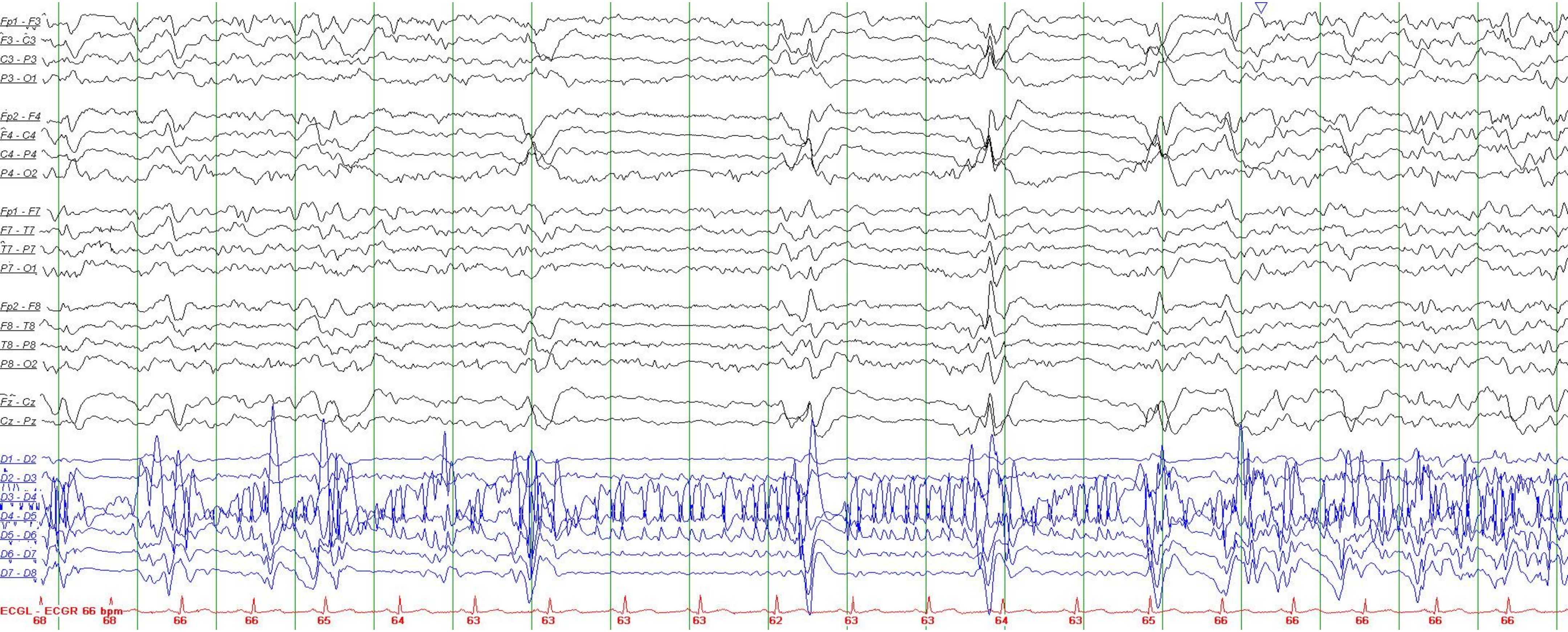

Fp1 - F3
F3 - C3
C3 - P3
P3 - O1
Fp2 - F4
F4 - C4
C4 - P4
P4 - O2
Fp1 - F7
F7 - T7
T7 - P7
P7 - O1
Fp2 - F8
F8 - T8
T8 - P8
P8 - O2
Fz - Cz
Cz - Pz
D1 - D2
D2 - D3
D3 - D4
D4 - D5
D5 - D6
D6 - D7
D7 - D8
ECGL - ECGR 60 bpm
60 60 59 59 59 59 63 66 65 64 65 62 62 61 60 59 60 60 60 60

EEG



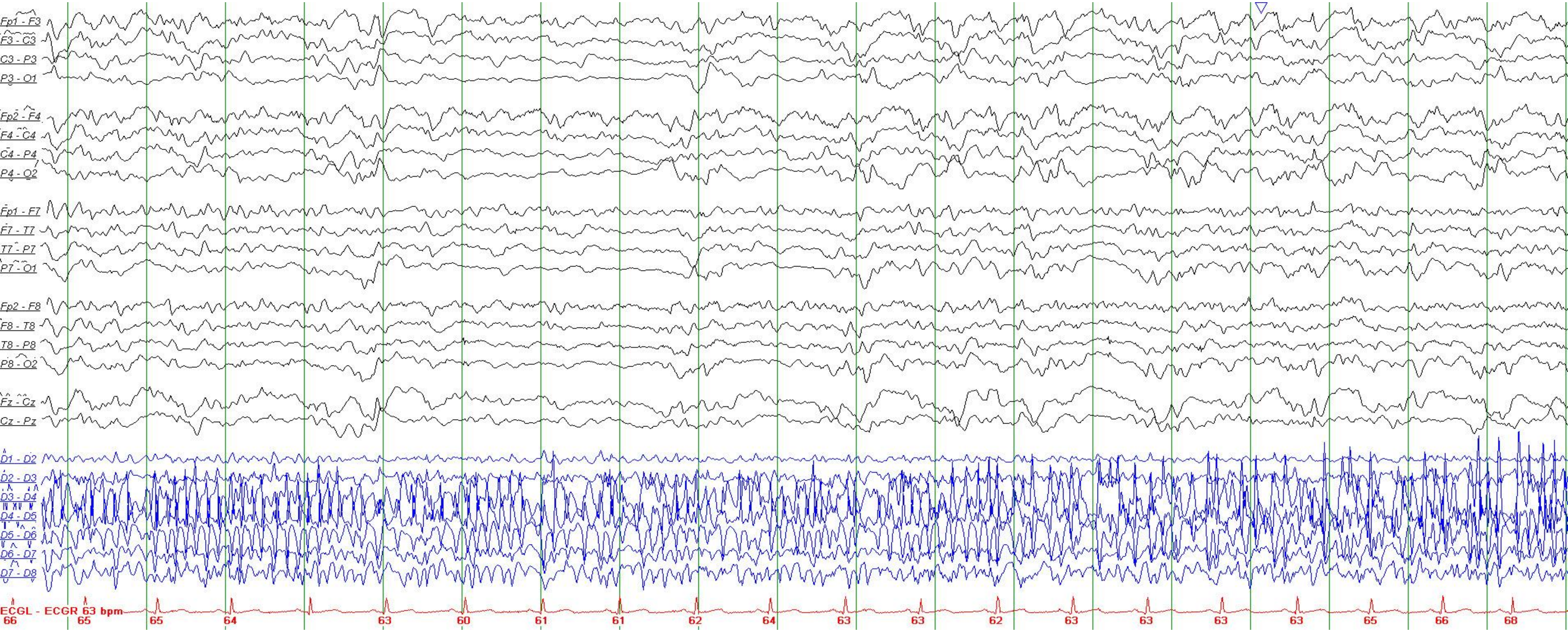
Here the depth seizure is interrupted briefly before resuming; with stuttering discharges in the depth, frontally predominant delta becomes more sharply contoured.

EEG



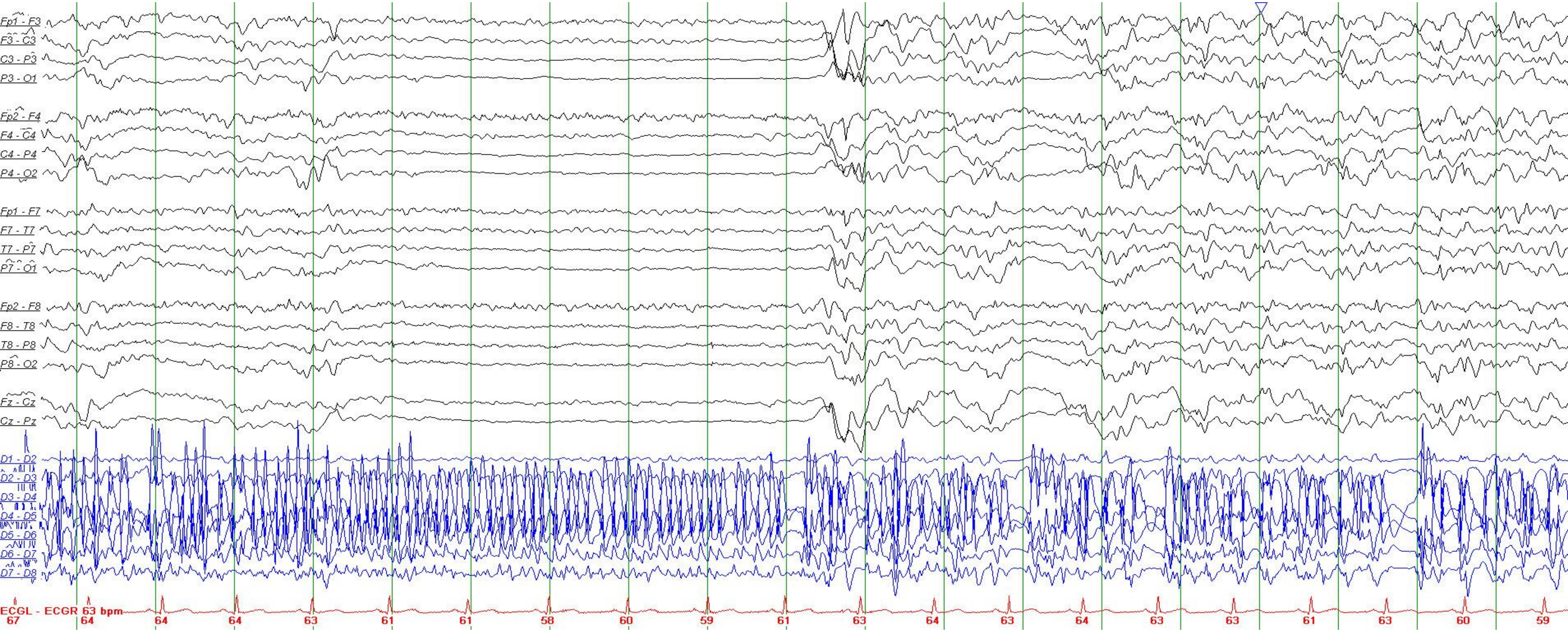
Fp1 - F3
F3 - C3
C3 - P3
P3 - O1
Fp2 - F4
F4 - C4
C4 - P4
P4 - O2
Fp1 - F7
F7 - T7
T7 - P7
P7 - O1
Fp2 - F8
F8 - T8
T8 - P8
P8 - O2
Fz - Cz
Cz - Pz
D1 - D2
D2 - D3
D3 - D4
D4 - D5
D5 - D6
D6 - D7
D7 - D8
ECGL - ECGR 66 bpm
68 68 66 66 65 64 63 63 63 63 62 63 63 64 63 65 66 66 66 66 66

EEG



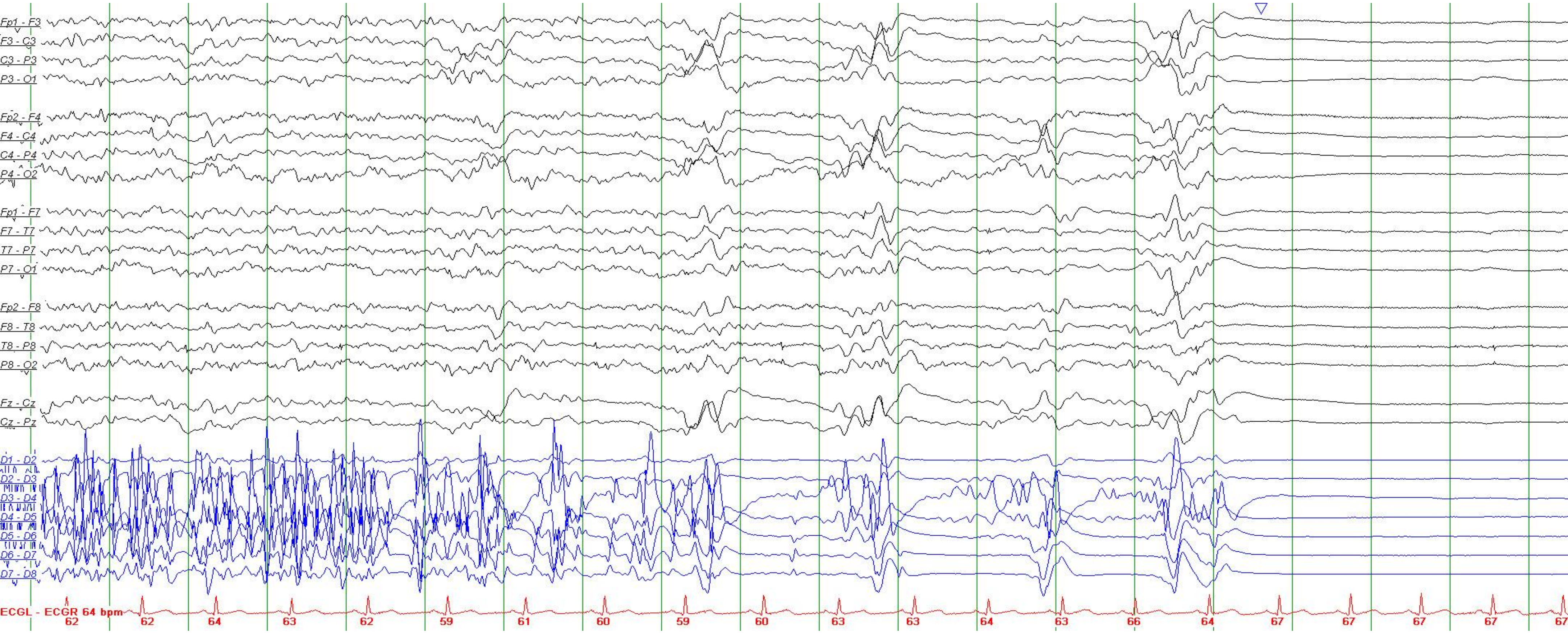
Fp1 - F3
F3 - C3
C3 - P3
P3 - O1
Fp2 - F4
F4 - C4
C4 - P4
P4 - O2
Fp1 - F7
F7 - T7
T7 - P7
P7 - O1
Fp2 - F8
F8 - T8
T8 - P8
P8 - O2
Fz - Cz
Cz - Pz
D1 - D2
D2 - D3
D3 - D4
D4 - D5
D5 - D6
D6 - D7
D7 - D8
ECGL - ECGR 63 bpm
66 65 65 64 63 60 61 61 62 64 63 63 62 63 63 63 63 65 66 68

EEG



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.

EEG



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.

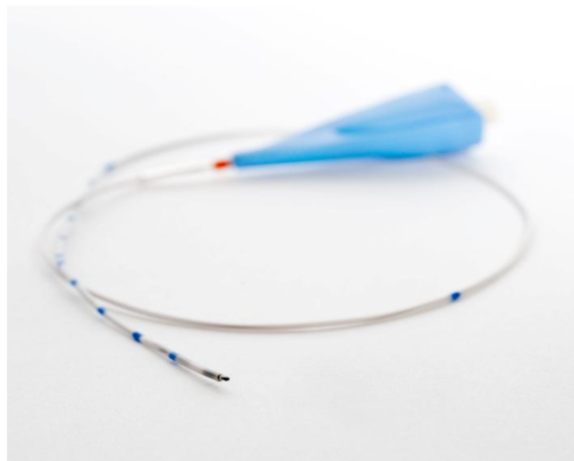
The **Hemedex Thermal Conductivity CBF Monitor can be Used to Measure Brain Water Content**

Ko S-B, et alet al. **Continuous Estimation of Brain Water Content Using Thermal Conductivity in Comatose Patients** ***JCBFM*** (submitted)

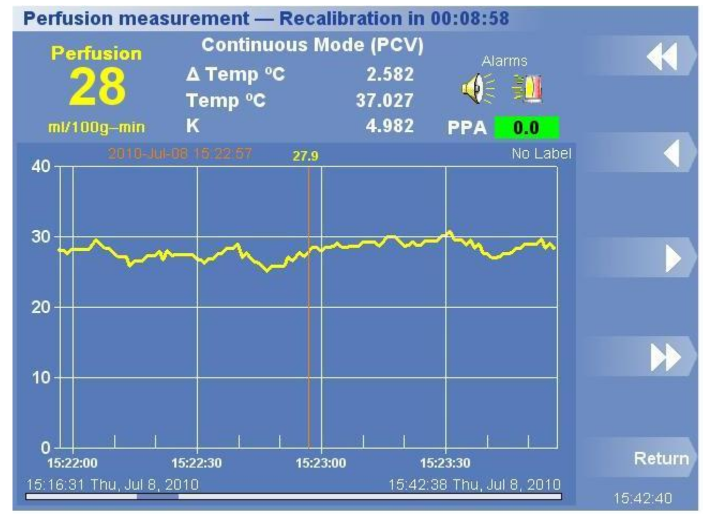
Components of the HEMEDEX System

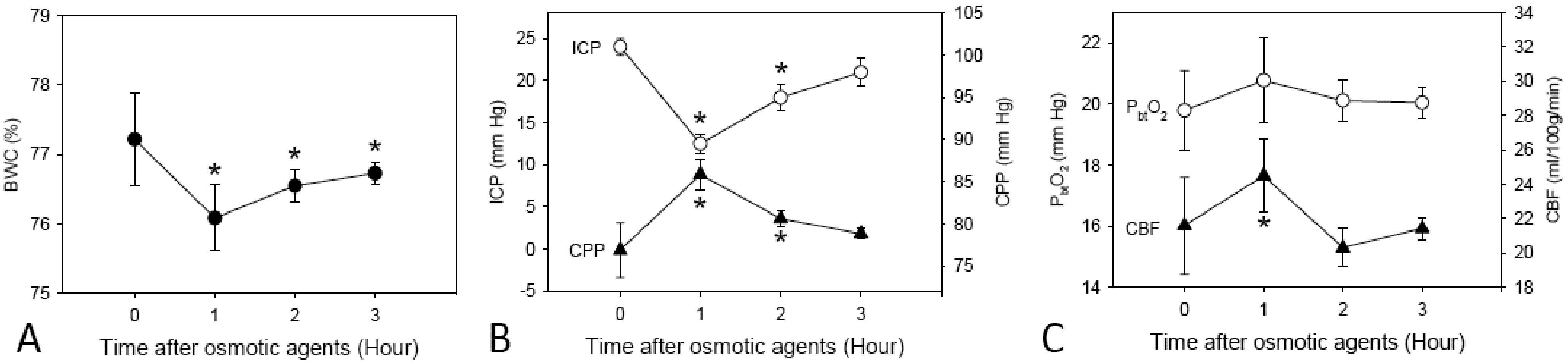
Bowman Perfusion Monitor (BPM)

QFlow 500 Probe



Trending of CBF in ml/100mg/min





Brain Water Content

ICP + CPP

PbtO2

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

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