Recent Advances in Central Nervous System Monitoring

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Evidence
Does CNS Monitoring Improve Outcome?

Empiricism
Reasoned Approach
The Need for Perioperative Neuromonitoring

- 150 patients/100,000 with stroke
- 0.8 - 10.0 % perioperative (overt or covert) stroke
- 10 % intraoperative awareness
- Cognitive dysfunction following cardiac surgery (< 60 %) or arthroplasty (< 40 %)
- > 10 % postoperative delirium
Pathophysiology of Acute Neurodegeneration

TBI, Hemorrhage, Stroke, Resuscitation

Principles of CNS-Monitoring

Upstream

- PaO2
- O2-Carrying Capacity
- CaO2
- Cardiac Output
- CPP
- O2-Transport

NIRS-DCS
(Diffuse Correlation Spectroscopy)

Supply-Demand-Ratio

- rSO2 (NIRS)
- Neuronal Function
  (EEG, EP)
- SjO2
- Tissue-PO2
- Microdialysis
  (Lactate, Pyruvate, L/P)

Metabolism

TCD & rCBF
(ICP)

Modified from Smith M. University College London Hospitals
Transcranial Doppler Sonography
Transcranial Doppler Sonography (TCD)
TCD Flow Spectra with Decreasing CPP
TCD Flow Spectra during Decreasing CPP
Cross Clamping during Carotid Endarterectomy
TCD with Decreases in CPP

Aortic Stent Implantation

CBFV (cm.s⁻¹)

MAP 84 mmHg
MAP 34 mmHg
during Stent Implantation
MAP 79 mmHg
Dynamic CBF Autoregulation

## Judgement: TCD

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<thead>
<tr>
<th>Quantitative</th>
<th>Global</th>
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<th>Non-invasive</th>
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<td>no</td>
<td>(yes)</td>
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### Remarks:
- Blood flow velocity rather than flow
- Probe may dislocate
- Permanent insonation exposes tissue to energy emission
- Injury from probe pressure and heat likely to occur
- Signal unavailable in 10% of patients
- No absolute threshold values identified
Jugular Bulb Oxymetry
(SvjO₂)
Jugular Bulb Oxymetry (SvjO$_2$)
Principle of SvjO₂-Monitoring

SaO₂ 100%  
SjvO₂ 75%  
CBF 60 ml/100g/min

CMRO₂ 3 ml/100g/min

SaO₂ 100%  
SjvO₂ 50%  
CBF 30 ml/100g/min

Thresholds of $\text{SvjO}_2$

- $\text{SvjO}_2 < 50\%$
- Confusion
- EEG-changes
- Coma
- Terminal depolarisations

SvjO₂ < 50% + lactate ↑

Average value
Judgement: SvjO$_2$

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Remarks:
- x-ray check for position, catheter requires repetitive control
- low sensitivity and specificity
- detection of balance between O$_2$ delivery and O$_2$ demand
- threshold: $< 50 \%$ plus lactate ↑
Near-infrared Spectroscopy
Near-infrared Spectroscopy (NIRS)

Noninvasive; emission of near-infrared light; measurement of absorption characteristics of oxy- and deoxyhemoglobin in arterial, capillary, and venous tissue.
NIRS in Carotid Surgery

NIRS in Cardiac Surgery
Preoperative Cerebral Oxygenation and Outcome

Heringlake M: Anesthesiology (2011)
NIRS Intervention Protocol in CABG Patients
30-Day Major Organ Morbidity and Mortality

Near-infrared Spectroscopy (NIRS)

Incidence of Postoperative Cognitive Dysfunction

### Judgement: NIRS

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<td>frontal only</td>
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**Remarks:**

- monitor of systemic changes in oxygenation and hemodynamics
- monitor of perioperative challenges  
  (e.g. posturing, x-clamp, OLV, aortic cannulation, deliberate hypotension)
- NIRS-targeted intervention protocols
- index for CNS homeostasis and systemic outcome
- signal contamination from extracranial sources
- no absolute threshold values ($\text{rsO}_2 < 55\%$ or $< 75 \%$ from baseline)
Monitoring of brain tissue $pO_2$
Monitoring of brain tissue $pO_2$

Martini RP. Resp Care (2013)
PtiO$_2$ vs. CBF and CPP Following TBI

Traumatic Brain Injury: PtiO$_2$ vs. ICP

# Judgement: Tissue pO$_2$ Monitoring

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**Remarks:**
- catheter should be placed in the tissue at risk
- calibration required prior to every measurement
- 1 hour run-in period
- MRI-3T compatible
- threshold: < 15-20 mmHg
Microdialysis
Microdialysis
Principles Of Microdialysis

**Entry**
(NaCl/Ringer/artificial CSF)
0.1-2.0 µl/min

**Exit to Microvial**

**online:**
- Glucose
- Pyruvate
- Glutamate
- Lactate
- Glycerol
- NOx

**offline:**
- Glucose
- Pyruvate
- Lactate
- NOx

**Ischemia / Hypoxia**
- Glucose
- Pyruvate
- Lactate
- NAD+
- NADH
- O2
- H2O
- CO2
- ++ATP

Modified from Sakowitz OW, UniversitätsKlinikum Heidelberg
Microdialysis vs. Brain Tissue pO₂ in SAH

PtiO₂ > 15 mmHg
PtiO₂ = 10 - 15 mmHg
PtiO₂ < 10 mmHg

## Judgement: Microdialysis

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**Remarks:**

- catheter should be placed in the tissue at risk
- due to insertion artifacts there is a period of unreliable values for at least 1 h after insertion
- glutamate and lactate/pyruvate ratio > 25-40 sensitive for development of ischemia. Lactate alone is insufficient
- thresholds for intervention uncertain
Brain Electrical Activity
Electroencephalogram (EEG)

Diagnosis and Pharmacodynamic Monitoring

Theophyllin-Intoxication

Phenytoin + Clonazepam

+ Thiopental
EEG-Pattern with Decreasing CPP
Cross Clamping during Carotid Endarterectomy

<table>
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<tr>
<th>Pre Clamp</th>
<th>Clamp</th>
<th>Reperfusion</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Pre Clamp EEG" /></td>
<td><img src="image2.png" alt="Clamp EEG" /></td>
<td><img src="image3.png" alt="Reperfusion EEG" /></td>
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CBF: 47 ml/100g/min  
CBF: 10 ml/100g/min  
CBF: 40 ml/100g/min

Concurrence of Low MAP, Low MAC, and Low BIS with Postoperative Death
Retrospective, 14000 Patients (3 clinical trials)

Willingham MD. Anesthesiology (2015)
RCTs Assessing Postoperative Delirium with Intraoperative BIS Guidance of Anesthesia

Whitlock EL. Anesth Analg (2014)
Triple Low (MAP / MAC / BIS) and Mortality
Prospective; 24.120 Non-Cardiosurgical Patients

Anesthesia insularism is coming to an end - strong relationship between intraoperative performance and long-term postoperative outcome

Sessler D. Anesthesiology (2012)
Intraoperative Suppression of EEG Postoperative Delirium

n = 727, prospective

Fritz BA. Anesth Analg (2016)
## Judgement: EEG

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- monitor of perioperative challenges (e.g. posturing, x-clamp, OLV, aortic cannulation, deliberate hypotension)
- always look into the “raw” EEG signal !
- all EEG indices are poor predictors of movement in response to noxious stimulation (spinal phenomenon)
- all EEG indices are insensitive to changes in analgesic state as a result of fluctuating opioid levels
- EEG suppression/deep anesthesia is related to adverse outcome
- using BIS reduces the incidence of postoperative delirium
Multimodal Monitoring

Cross validation, artefact rejection
Optimization of CBF and oxygenation
Withholding potentially dangerous therapy for those without ischemia/hypoxia