Monitoring Cerebral Perfusion: Update and New Developments

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*
Xe133 CBF
TCD
Jug Sat
CMRO2
Carotid Doppler
NIRS
Monitoring Cerebral Perfusion

- $^{133}$Xenon intermittent
- Jugular bulb saturation invasive, mixed venous
- TCD
- Cerebral oximetry

Dynamic cerebral autoregulation
Perioperative Multimodality Neuromonitoring

1. Technology
2. Evidence for benefit
3. Cerebral Autoregulation
4. Extracerebral tissue
5. Ultrasound Tagged NIRS - CBF
TransCranial Doppler: Flow, Emboli

MCA flow during Pulsatile perfusion during CPB

TCD: - MCA waveform - emboli
Transcranial Doppler

- Transtemporal ‘window’: inadequate in 20-30% adults
- Flow velocity ~ blood flow: constant arterial diameter (PaCO2, vasodilators)
- Insonation angle $\Theta = \text{velocity}$: unsteady, susceptible to movement
- Emboli: poor discrimination, micro air = macro particles (multifrequency?)
Cerebral Oximetry: Technology

- Robust: adhesive patches, frontal access
- Continuous, non-invasive
- Low cerebral saturation
  - preoperative: poor prognosis, > Euroscore
  - intraoperative: cognitive dysfunction, major organ dysfunction

- Treatment Algorithm
  - Improve outcomes

- Dynamic Cerebral Autoregulation
- Extracerebral Contamination
Evidence for Benefit

- Preoperative Risk Assessment
- Intraoperative Desaturation
- Treatment Algorithm
- Directed Interventions
Preoperative Risk Assessment

Preoperative Cerebral Oxygen Saturation and Clinical Outcomes in Cardiac Surgery


What We Know about This Topic
- Intropreoperative cerebral oxygen saturation (ScO₂) monitoring has been used to assess the adequacy of cerebral oxygen delivery to demand.

What This Article Tells Us That Is New
- Preoperative ScO₂ concentrations are reflective of baseline severity of cardiopulmonary dysfunction, associated with short- and long-term mortality and morbidity, and may add to preoperative risk stratification in patients undergoing cardiac surgery.

Cerebral Oximetry
Monitoring the Brain as the Index Organ
Anesthesiology 2011; 114:12-3
John M. Murka

"Preoperative ScO2 levels are reflective of the severity of cardiopulmonary dysfunction, and are associated with short and long-term mortality and morbidity"
Low cerebral saturation: Preoperative

20 neonates without pre-existing brain damage underwent arterial switch Sx

“Patients with lower preop ScO2 had lower DQ at 30-36 mo...”

“Preoperative cerebral desaturation may be underestimated as possible cause of adverse postoperative outcome”

Cerebral oxygen saturation and electrical brain activity before, during, and up to 36 months after arterial switch procedure in neonates without pre-existing brain damage: its relationship to neurodevelopmental outcome

Abstract: Objective: To monitor the pattern of cerebral oxygen saturation (rSat), by use of NIRS, in term infants before, during and after the arterial switch operation and to evaluate its relation to neurodevelopmental outcome. Methods: In 20 neonates without pre-existing brain damage hemodynamics and cerebral oxygen saturation (AO2-sat) were recorded simultaneously with rSat and amplitude-integrated EEG (aEEG) from 4 h to 12 h before up to 36 h after cardiopulmonary bypass (CPB) and short duration of cardiac arrest during deep hypothermia (DHCA). The Bayley’s developmental scale was performed at 30 months. Results: Before surgery rSat was < 50% in 16 patients. During CPB rSat increased to normal values, with a sharp decrease during brief CA (median 6.5 min). Post-CPB rSat showed a transient decrease (30-45%) despite normal PAO2 with sustained normalization after 6-26 h. Recovery time of the rSat seemed longer when pre-operative rSat was below 35%, and for lower minimum nasopharyngeal temperature and longer duration of CPB and of DHCA.

Keywords: Newborn - Arterial switch operation - Cerebral oxygenation - Electrical brain activity - Neurodevelopmental outcome

Intraoperative Desaturation

Cerebral Oxygen Desaturation Is Associated With Early Postoperative Neuropsychological Dysfunction in Patients Undergoing Cardiac Surgery

Cerebral Oxygen Desaturation Predicts Cognitive Decline and Longer Hospital Stay After Cardiac Surgery

Noninvasive cerebral oxygenation may predict outcome in patients undergoing aortic arch surgery

Congenital Heart Disease

Relationship of Intraoperative Cerebral Oxygen Saturation to Neurodevelopmental Outcome and Brain Magnetic Resonance Imaging in Children with Congenital Heart Disease

Intraoperative desaturation implies adverse postoperative outcomes
“What can be done? It’s like watching a traffic accident...”
Low cerebral saturation: Treatment Algorithm

A Proposed Algorithm for the Intraoperative Use of Cerebral Near-Infrared Spectroscopy

André Denault, MD, FRCPC, ABIM-CCM,
Alain Deschamps, MD, FRCPC, PhD,
and John M. Murkin, MD, FRCPC
Figure 3. Aortic dissection with unilateral cerebral perfusion via innominate artery. Immediate profound decrease in left rSO₂ followed by perfusion via left carotid artery cannula with restoration of left rSO₂. 1, induction of anesthesia; 2, onset of CPB; 3, cooling on CPB; 4, 18°C onset SCP via innominate artery; 5, profound left desaturation; 6, perfusion via left carotid cannula. This unilateral desaturation is most probably because of incomplete circle of Willis.

Figure 4. Brain desaturation during cardiac transplantation. (A) A reduction down to 43% in brain saturation was observed. (B) Despite adequate mean arterial pressure (from radial and femoral transducers) during cardiopulmonary bypass, the desaturation was associated with an increase in the left internal jugular vein (LIJV) pressure of 65 mm Hg. At that point, the cardiothoracic surgeon decided to reposition the superior vena cava (SVC) cannula that was occluding cerebral venous return. The brain oximetry value increased. (C) The LIJV pressure decreased to 12 mm Hg.
CAS meeting 2010: Denault and colleagues report >90% success restoring basal ScO2
Directed Interventions: MOMM

**Monitoring Brain Oxygen Saturation During Coronary Bypass Surgery: A Randomized, Prospective Study**

John M. Murkin, MD, FRCPC
Sandra J. Adams, RN*
Richard J. Novick, MD, FRCSC$
Mackenzie Quantz, MD, FRCPS$
Daniel Bainbridge, MD, FRCPC*
Ivan Iglesias, MD*

**BACKGROUND:** Cerebral deoxygenation is associated with various adverse systemic outcomes. We hypothesized, by using the brain as an index organ, that interventions to improve cerebral oxygenation would have systemic benefits in cardiac surgical patients.

**METHODS:** Two-hundred coronary artery bypass patients were randomized to either intraoperative cerebral regional oxygen saturation (rSO$_2$) monitoring with active display and treatment intervention protocol (intervention, n = 100), or underwent blinded rSO$_2$ monitoring (control, n = 100). Predefined clinical outcomes were assessed by a blinded observer.

**RESULTS:** Significantly more patients in the control group demonstrated prolonged cerebral desaturation ($p = 0.014$) and longer duration in the intensive care unit ($p = 0.029$) versus intervention patients. There was no difference in overall incidence of adverse complications, but significantly more control patients had major organ morbidity or mortality (death, ventilation >48 h, stroke, myocardial infarction, return for re-exploration) versus intervention group patients ($p = 0.048$). Patients experiencing major organ morbidity or mortality had lower baseline and mean rSO$_2$, more cerebral desaturations and longer lengths of stay in the intensive care unit and postoperative hospitalization, than patients without such complications. There was a significant ($r^2 = 0.29$) inverse correlation between intraoperative rSO$_2$ and duration of postoperative hospitalization in patients requiring ≥10 days postoperative length of stay.

**CONCLUSION:** Monitoring cerebral rSO$_2$ in coronary artery bypass patients avoids profound cerebral desaturation and is associated with significantly fewer incidences of major organ dysfunction.

(Archee Ansl 2007:104:51-6)
Directed Interventions: Diabetic MOMM

Monitoring Brain Oxygen Saturation During Coronary Bypass Surgery Improves Outcomes in Diabetic Patients: A Post Hoc Analysis

Table 3. Thirty-Day Postoperative Morbidity and Mortality In All Diabetic Patients*

<table>
<thead>
<tr>
<th></th>
<th>Control (n = 29)</th>
<th>Intervention (n = 28)</th>
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<tr>
<td>Myocardial infarction, n</td>
<td>1</td>
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<tr>
<td>Postoperative IABP use, n</td>
<td>2</td>
<td>2</td>
<td>.681</td>
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<td>New-onset stroke, n†</td>
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<td>.508</td>
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<tr>
<td>Sternal infection, n</td>
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<td>.028</td>
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<tr>
<td>Mediastinitis, n†</td>
<td>1</td>
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<td>.508</td>
</tr>
<tr>
<td>Arrhythmia requiring treatment, n</td>
<td>1</td>
<td>0</td>
<td>.508</td>
</tr>
<tr>
<td>Reoperation for bleeding, n†</td>
<td>0</td>
<td>1</td>
<td>.491</td>
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<tr>
<td>Surgical reintervention, n†</td>
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</tr>
<tr>
<td>Renal failure requiring dialysis, n†</td>
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<tr>
<td>Death, n†</td>
<td>0</td>
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<tr>
<td>Ventilation time, min</td>
<td>1096 ± 1778</td>
<td>649 ± 313</td>
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<tr>
<td>Ventilation time &gt;24 h, n</td>
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<td>Ventilation time &gt;48 h, n†</td>
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<td>ICU time, d</td>
<td>2.8 ± 4.1</td>
<td>1.4 ± 1.0</td>
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<tr>
<td>ICU time &gt;5 d, n</td>
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<tr>
<td>Total no. of ICU days</td>
<td>80</td>
<td>39</td>
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<tr>
<td>Length of stay, d</td>
<td>8.2 ± 6.1</td>
<td>5.7 ± 1.7</td>
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<td>Length of stay ≥7 d, n</td>
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<td>Readmission to hospital within 30 d, n</td>
<td>4</td>
<td>3</td>
<td>.520</td>
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<td>Patients ≥1 complication, n</td>
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<td>MOMM, n†</td>
<td>4</td>
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<td>No. of events/patients, n</td>
<td>34/13</td>
<td>9/6</td>
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</table>

*Data are categorical or presented as the mean ± SD. IABP indicates intra-aortic balloon pump; ICU, intensive care unit; MOMM, major-organ morbidity and mortality.
†Indicates variables comprising MOMM, as derived from Society of Thoracic Surgeons database analysis [Shroyer 2003].
Directed Interventions: delirium
Cerebral Oximetry?
Cerebral Pressure Autoregulation

**Classical Cerebral Autoregulation**
- ‘flat’

**Dynamic Autoregulation**
- ‘fluctuant’

*ie. microcirculatory dynamics*
Dynamic Autoregulation: ‘fluctuant’

*ie. microcirculatory dynamics*

- Instantaneous correlation between TCD $\Delta$MCA-FV vs $\Delta$ICP
- Modification: $\Delta$ NIRS vs $\Delta$ MAP
- Moving average (300 sec)
- Probability coefficient: $\phi - 1.0$
  *ie. no correlation vs complete correlation (presence vs absence autoregulation)*

- Functional cutoff: $< 0.4$

DAR: Very sensitive, variable onset/duration
Risks for impaired cerebral autoregulation during cardiopulmonary bypass and postoperative stroke

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Editor’s key points
- Impaired cerebral autoregulation may predispose to ischaemic brain injury.
- The authors found that impaired cerebral autoregulation occurred in 20% of patients during cardiopulmonary bypass.
- An autoregulation index measured with near infrared spectroscopy was able to identify impaired autoregulation.
- Impaired autoregulation was more common in patients developing stroke after surgery than those without a stroke.

Background. Impaired cerebral autoregulation may predispose patients to cerebral hyperperfusion during cardiopulmonary bypass (CPB). The purpose of this study was to identify risk factors for impaired autoregulation during coronary artery bypass graft, valve surgery with CPB, or both and to evaluate whether near-infrared spectroscopy (NIRS) autoregulation monitoring could be used to identify this condition.

Methods. Two hundred and thirty-four patients were monitored with transcranial Doppler and NIRS. A continuous, moving Pearson’s correlation coefficient was calculated between mean arterial pressure (MAP) and cerebral blood flow (CBF) velocity, and between MAP and NIRS data, to generate the mean velocity index (Mx) and cerebral aximetry index (COX), respectively. Functional autoregulation is indicated by an Mx and COX that approach zero (no correlation between CBF and MAP); impaired autoregulation is indicated by an Mx and COX approaching 1. Impaired autoregulation was defined as an Mx ≥0.40 at all MAPs during CPB.

Results. Twenty per cent of patients demonstrated impaired autoregulation during CPB. Based on multivariate logistic regression analysis, time-averaged COX during CPB, male gender, PaCO2, CBF velocity, and preoperative aspirin use were independently associated with impaired CBF autoregulation. Perioperative stroke occurred in six of 47 (12.8%) patients with impaired autoregulation compared with five of 207 (2.7%) patients with preserved autoregulation (P = 0.011).

Conclusions. Impaired CBF autoregulation occurs in 20% of patients during CPB. Patients with impaired autoregulation are more likely than those with functional autoregulation to have perioperative stroke. Non-invasive monitoring autoregulation may provide an accurate means to predict impaired autoregulation.


Keywords: cardiac surgery; cardiopulmonary bypass; cerebral autoregulation; stroke

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Issues:
Cerebral Oximetry: Extracerebral

Cerebral NIRS s
85-95% intracerebral
5-15% extracerebral

Confounds:
Scalp edema,
Hematoma
SDH
Frontal sinus

My brain hurts!
Cerebral Oximetry:
Extracerebral Contamination

Elliptical photon path depth approx 1/3 receiver/transmitter separation

Subtraction algorithm to separate superficial from deep tissue
Cerebral Oximetry: Extracerebral Contamination

Impact of Extracranial Contamination on Regional Cerebral Oxygen Saturation
A Comparison of Three Cerebral Oximetry Technologies

Sophie N. Davie, B.Sc.,* Hilary P. Grocott, M.D., F.R.C.P.C.†

Anesthesiology 2012; 116:834 - 40

“...a significant reduction in regional cerebral oxygen saturation measurements in all three NIRS devices studied”

“Extracerebral contamination appears to significantly affect NIRS measurements of cerebral oxygen saturation”
Cerebral Oximetry: Extracerebral Contamination

Effect of phenylephrine and ephedrine bolus treatment on cerebral oxygenation in anaesthetized patients


Phenylephrine but not Ephedrine Reduces Frontal Lobe Oxygenation Following Anesthesia-Induced Hypotension

Peter Nissen, Patrice Brassard, Thomas B. Jørgensen, Niels H. Secher
“skin oxygenation contributes about 30% to the NIRS signal...”

“...nevertheless spatial resolved NIRS is able to detect cerebral deoxygenation associated with hyperventilation and systemic hypoxic exposure...”
What’s New?
UTLight technology

- Photons that travel through the path of the ultrasound wave are “tagged” and can be identified upon detection, by detecting an artificial Doppler shift induced by the moving ultrasound waves.
- Ultrasound waves are directional, and travel slowly.
- Thus the path of the photons is measured and not assumed to be equal – The profile of the light is measured along the ultrasound path.
- Oxygen saturation is calculated from the ratio of three different profiles (at different wavelengths), at a certain depth.
- Flow is calculated from the flow induced Doppler shift of the light profile.

Collected Light Profile

- High Blood Flow
- Low Blood Flow

Depth (mm)
New: Ultrasound Tagged Cerebral NIRS
Acousto-optic Coupling

• UT-NIRS allows measures of microcirculatory CBF
• Doppler U/S focusing removes extracerebral signal
Oximetry and Flow Following Acetazolamide

Concurrent measurement with CerOx and $^{133}$Xe SPECT
CFI: Direct NIRS Monitoring of CBF

Real time correlation of TCD vs CFI

Emboli post AVR

Microcirculatory vasodilatory response to microgaseous embolic ischemia

Murkin JM, et al
UWO, London, ON
Summary

• Cerebral oximetry reflects oxygen saturation in high risk/'protected' organ: brain
• If brain sats low, either:
  global hypoperfusion
  or
  localized brain ischemia
• Cerebral oximetry allows further preoperative quantification of risk/optimization
• ‘false’ positives d/t extracerebral tissue v/c (phenylephrine) may exacerbate
• \(\rightarrow\) newer technology (precise ScO2 and CBF)
Thank you

Maxwelton Braes, Harrington, Ontario