Near Infrared Cerebral Oximetry: Is it ready for prime time yet?

Objectives: At the end of the talk the participants will have an understanding of the technology of cerebral oximetry, its clinical applications and impact on outcomes, currently available commercial devices and the limitations of cerebral oximetry.

Introduction:

Frans Jobis first described the measurement of cerebral oxyhemoglobin content by a spectrophotometric technique in 1977. Although this was met with much enthusiasm, 30 years later, near infrared spectroscopy based cerebral oximeter still remains a monitor looking for its proper place in the pantheon of monitoring.

Technology of Cerebral oximetry: Light in the near-infrared (700-1300 nm) range has three important physical properties that make it useful for diagnostic assessment: it penetrates tissue; it is non-ionizing; and it is absorbed differentially by relevant chromophores depending on their oxygen-binding state. When near-infrared light is emitted across a tissue (e.g. the brain) and detected at its exit, absorption of the light can be used to calculate chromophore concentration using variants of the Beer-Lambert equation. All optical spectrometers consist of the same basic components: a light source of a known intensity and wavelength; a light detector to measure the intensity of the light exiting the tissue; and a computer to translate the changes in light intensity to clinically useful information such as the concentrations of HbO2, Hb or oxidized cytochrome aa3.

When photons impinge on biological materials, their transmission depends on a combination of reflectance, scattering and absorption effects. A light source (light emitting diode or laser source) emits near-infrared light which passes through a “banana-shaped” reflectance path in the frontal cerebral cortex to two to three detectors placed 3-5 cm from the emitter. Absorption occurs at specific wavelengths, determined by the molecular properties of the material in the light path. Optical path length for reflected light is linearly related to the spacing between
the transmission and receiving sites and so many of the NIRS measurement instruments place the transmitting diode and light detector several centimeters apart on the head. Although this spacing results in a measurable signal intensity, it affects the amount and depth of tissue monitored. On a practical level, the available instruments space their transmitting and receiving sites differently, thus measuring different quantities and depths of tissue which makes comparisons between instruments difficult.

Shallow arcs of light travel across skin and skull but do not penetrate the cerebral tissue. Deep arcs of light cross skin, skull, dura and cortex. Subtracting the absorbance measured in the narrow arc from that measured in the deep arc leaves absorbance that is due to intracerebral chromophores. This is one of the distinguishing characteristics of cerebral oximeters compared to pulse oximeters. Cerebral oximeters use spatial resolution techniques to differentiate cortical from extracranial blood, whereas pulse oximeters differentiate pulsatile (arterial) from non-pulsatile (venous/capillary) blood. Cerebral oximetry measures predominantly venous saturation (75:25 or 85:15, depending on age, model used). NIRS could be a surrogate for jugular venous oxygen saturation monitoring, without being invasive. NIRS does not depend on pulse, blood pressure or body temperature. This makes the technique ideally suited for monitoring oxygenation during cardiopulmonary bypass, hypothermic circulatory arrest, during shock or cardiovascular collapse.

Validation of NIRS: Studies in humans has focused on measuring jugular venous oxygen saturation under controlled experimental and clinical conditions and its correlation with cerebral oximetry. NIRS correlates well with jugular venous O₂ saturation as well as superior vena cava O₂ saturation. NIRS values have also been validated in piglet studies that correlated rSO₂ values and metabolic markers of cerebral oxygenation such as cerebral adenosine triphosphate (ATP) and phosphocreatine (PCr) and brain lactate concentrations. NIRS data are available for children with heart disease, with or without cyanosis. Human and animal data support the ischemic threshold value of approximately 45%. Prolonged periods of
NIRS values in this range has been correlated with adverse postoperative neurologic MRI findings in newborns undergoing surgery for HLHS. In piglets increasing lactates and decreasing ATP concentrations were noted at ScO2 values of 33-44%.

**Clinical Applications:** In order to use the devices, one or two cerebral oximeter probes are placed on the forehead below the hairline. In the case of Somanetics, each skin probe has one LED light-source that is sensed by two separate light sensors, one at 3 cm from the source, the other at 4 cm. The proximal sensor detects light absorbed by extra-cranial tissues and is subtracted from the total signal detected by the distal sensor, leaving only the intracranial contribution. The source-detector distance determines the depth of the light path with a distance of 4 cm necessary for intracranial measurement about 2 cm below the probe.

The landmark observational study using multi-modality neurological monitoring by Austin et al must be credited with the interest in NIRS for pediatric open heart surgery. These authors reported a 26% postoperative adverse neurological outcome when intraoperative desaturations were not treated versus only 6% when the changes were treated. Cerebral oxygen saturation is a balance between oxygen delivery and utilization. If the latter remains unchanged then any decrements in cerebral saturation must be due to decreased cerebral oxygen delivery. This could be due to decrease in arterial saturation, Hb or cerebral blood flow. Hence if cerebral O2 saturation decreases, in the face of normal SpO2, its important to decide why cerebral oxygen delivery has changed. Conditions of increased utilization include hyperthermia, seizures, change in level of arousal and must be treated. During initiation of bypass one of the common causes for decreases in rSO2 is arterial cannula malposition or occlusion to venous drainage, which decreases the cerebral perfusion pressure and reduces CBF. Although NIRS has remained deeply rooted in the realm of pediatric heart surgery, its use should be extended to other vulnerable populations, such as children undergoing cardiac catheterizations, premature neonates undergoing surgical procedures where inadvertent hypocarbia could reduce cerebral blood flow and worsen the periventricular leukomalacia and lead to adverse neurodevelopmental outcomes.
Recently an article addressed the issue of “Does intraoperative cerebral oximetry during cardiac surgery lead to improved clinical outcomes” by reviewing the literature of over 488 papers concluded that judicious use of cerebral oximeter reduced major organ morbidity and mortality and the lack of use-associated risk at a modest expense support the use of the device routinely during open heart surgery.

**Devices on the Market in 2010:**

Invos 5100 b, c from Somanetics Inc, Troy, Mi; 2 wave lengths of light; measures reduced and oxygenated Hb; reports rSo2%; Trend device. FDA approved Large and small sensors. 4 Channels for monitoring. Somanetics also has FDA approval for using its probes on somatic sites as a surrogate for organ perfusion such as kidney, liver, gut.

Foresight, CAS Medical Systems Inc, Branford CT: 4 wavelength, oxy and reduced HB and reports cerebral tissue oxygen saturation (%SctO2). Absolute measurement of cerebral tissue oxygen saturation. FDA approved; Large, medium and small sensor

Niro 500, Hamamatsu, Japan: 4 wavelengths, reduced and oxy Hb and cytochrome oxidase, reports TOI (tissue oxygenation index); not FDA approved in the USA.


The devices are hard to compare; each uses proprietary algorithm, and report the results differently.

**Additional Uses:**

NIRS can be useful in determining pressure passivity of cerebral circulation. That is when autoregulation of CBF is lot. In preterms undergoing PDA ligation periods of pressure passivity with decreases in MAP and associated reductions in cerebral saturation. This has important therapeutic implications. Routine monitoring during the pre and intraop and post operative periods for pressure passivity has important implications for cerebral outcomes in neonates with and without heart disease.

**Limitations:**
1. Lack of standardization among devices making comparisons impossible.  
2. No real gold-standard for calibration.  
3. The current oximeters measure a small volume of brain tissue from which one must generalize well being of the whole brain.  
4. No clear guidelines on its use for children presenting for non-cardiac surgery. 

**Conclusion:** Despite the limitations of the technology and paucity of large studies showing a clear benefit we must adopt this technology and use it when we care for sick neonates or those with heart disease where detecting ongoing cerebral desaturation to ischemic levels in the face of arterial oxygen desaturation is otherwise impossible. Neurological outcome studies are expensive, take decades and by the time the results are available the damage may be long done.

References:


Hunaid A. Vohra, Amit Modi and Sunil K. Ohri: *Interact CardioVasc Thorac Surg* 2009;9:318-322; originally published online May 15, 2009; Does use of intra-
operative cerebral regional oxygen saturation monitoring during cardiac surgery lead to improved clinical outcomes?