Review Article

Near-infrared spectroscopy

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Abstract

Tissue ischaemia can be a significant contributor to increased morbidity and mortality. Conventional oxygenation monitoring modalities measure systemic oxygenation, but regional tissue oxygenation is not monitored. Near-infrared spectroscopy (NIRS) is a non-invasive monitor for measuring regional oxygen saturation which provides real-time information. There has been increased interest in the clinical application of NIRS following numerous studies that show improved outcome in various clinical situations especially cardiac surgery. Its use has shown improved neurological outcome and decreased postoperative stay in cardiac surgery. Its usefulness has been investigated in various high risk surgeries such as carotid endarterectomy, thoracic surgeries, paediatric population and has shown promising results. There is however, limited data supporting its role in neurosurgical population. We strongly feel, it might play a key role in future. It has significant advantages over other neuromonitoring modalities, but more technological advances are needed before it can be used more widely into clinical practice.

Key words: Brain ischaemia, Near-infrared spectroscopy, Neuromonitoring

BACKGROUND

Measurement of tissue oxygenation is of paramount importance in critical care settings since tissue ischaemia can be a major contributor to morbidity and mortality. Estimation of global or systemic oxygenation with the help of parameters like pulse oximetry, blood gas analysis, mixed venous oxygen saturation are well established, but monitoring of regional tissue oxygen saturation is slowly gaining acceptance.[1] Umpteen methods of measuring cerebral oxygenation are in vogue such as jugular venous oximetry, brain tissue oxygen tension, transcranial Doppler (TCD) and electroencephalogram (EEG). However, all these have significant limitations.[2]

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Near-infrared spectroscopy (NIRS) is a non-invasive means of determining real-time changes in regional oxygen saturation (rSO_2) of cerebral and somatic tissues.[3] Use of NIRS is slowly gaining popularity among physicians.

Jöbsis in 1977 initially observed that light in the NIR light spectrum (700–950 nm) can traverse biological tissue (myocardium and brain) because of the relative transparency of tissue to light in this wavelength range.[4] NIRS devices rely on the Beer-Lambert law, which states that one can measure a concentration of a substance based on its absorption of light. The absorption is proportional to the concentration of certain chromophores, mainly iron in haemoglobin and copper in cytochrome aa3. In the brain, the primary light-absorbing molecules within the NIR range are metal complex chromophores: Oxyhaemoglobin, deoxyhaemoglobin and cytochrome c oxidase. Because the most haemoglobin in tissue is in the venous circulation, NIRS gives a venous-weighted relative oxygen index of tissue beneath the probe.[5,6]

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PRINCIPLE

NIR light can be used to measure the regional cerebral tissue oxygen saturation. This technique uses principles of optical spectrophotometry. However, because of the poor signal-to-noise ratio as a result of the low intensity of transmitted light, most commercially available devices use reflectance-mode NIRS, in which receiving optodes are placed ipsilateral to the transmitter and exploit the fact that photons transmitted through a sphere will traverse an elliptical path in which the mean depth of penetration is proportional to the transmitter and receiver optode separation. Fundamental challenges posed in utilising transcranial reflectance NIRS to measure cerebral tissue oxygen saturation include the potential requirement for knowledge of the photon path length, the presence of non-haeme chromophores and variable light absorption by overlying extracerebral tissue.

MONITORS AVAILABLE

Worldwide many companies are marketing NIRS based devices to measure cerebral oximetry. But in India, two companies are marketing these devices. First is Sensmart X-100 by Nonin Medical Inc., (Minneapolis, MN, USA) and other is INVOS 3100 by Medtronic (Jacksonville, FL, USA) [Figure 1].

TECHNIQUE

NIRS sensors are applied on either side of forehead on a clean, dirt free, non-greasy skin. The sensors adhere to skin and evaluate the area underneath. The emitting and detecting devices are often referred to as the optodes. In adults, bilateral frontal cerebral oximetry is used to monitor perfusion to at risk areas of grey matter within cerebral cortex in the watershed areas between the anterior cerebral artery and middle cerebral artery. The smaller head circumference of neonates and children permits greater depth of penetration and assessment of subcortical tissue oxygenation. The sensors illuminate up to a volume of 10 ml of hemispherical tissue. Light is generated at specific wavelengths typically by light-emitting diodes, and is usually detected by silicon photodiodes. Many systems incorporate 2 or more channels allowing monitoring of multiple tissue regions of interest simultaneously.

The radial depth will depend on the interoptode distance. The optodes are placed on one side of the forehead with an interoptode spacing of 4–7 cm. NIR time resolved spectroscopy with functional maximal optode spacing of 4 cm measure cerebral haemodynamic responses optimally and quantitatively [Figure 2]. The normal values of rSO_2 are reported to be 60–80%. A 20% decline in rSO_2 from baseline is considered to be an ischaemic threshold. In general, a decrease in rSO_2 is reflective of an increase in oxygen extraction and debt as a result of increased metabolism, decreased perfusion and/or stagnant perfusion. High rSO_2 may be indicative of increased perfusion, decreased tissue bed metabolism and/or less oxygen extraction.

CLINICAL APPLICATIONS

The proper management of brain oxygenation is one of the principal endpoints of all anaesthesia procedures, but the brain remains one of the least monitored organs during clinical anaesthesiology. There are some medical procedures where iatrogenic brain ischaemia is present, including carotid endarterectomy (CEA) in patients with high-grade carotid artery stenosis, temporary clipping in brain aneurysm surgery, hypothermic circulatory arrest for aortic arch procedures and others in which the pathology itself generates brain ischaemia, such as traumatic brain injury (TBI) and stroke.

Cardiac surgery

The most common application of NIRS is the assessment of cerebral oxygenation during and following

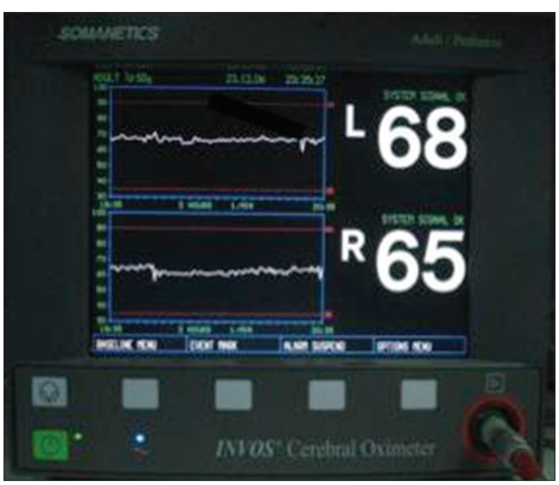

Figure 1: INVOS cerebral oximeter

Figure 2: Bilateral frontal optode placement

cardiac surgery. This is very useful in patients on cardiopulmonary bypass (CPB) where poor neurological outcome like stroke and postoperative cognitive dysfunction are a concern for all clinicians. NIRS use has been found to decrease cerebral desaturation events during CPB, fewer strokes, less postoperative major organ morbidity (mechanical ventilation, myocardial infarction).[7,8] Similarly low rSO_2 levels below 50% have been associated with increased risk of postoperative cognitive dysfunction and prolonged hospital stay by about three-fold.[9,10]

NIRS use is now widespread in cardiac surgery. In fact, NIRS use has been maximally adopted by the cardiac centres performing high-risk procedures such as aortic arch repair and deep hypothermic circulatory arrest. Many centres have now formulated algorithms for the clinical use of NIRS monitors in cardiac surgery patients.[11]

Carotid endarterectomy

Various monitoring techniques like EEG, TCD, evoked potential monitoring have been used to predict cerebral ischaemia in CEA. NIRS being simple to use has also been extensively used to monitor cerebral perfusion. It can be a valuable tool to detect cerebral ischaemia during CEA. Various cut-off values like a decline of >20% from baseline was initially recommended[12] but now various studies recommend a decrease in rSO_2 of more than 12% to be reliable, sensitive and reliable specific threshold for brain ischaemia.[13]

Paediatrics

NIRS is being increasingly used both intraoperatively and postoperatively for paediatric cardiac surgery,[14] neurosurgery and in the critical care setting for low birth weight infants, premature children at risk for apnoea.[15] It also appears useful for measuring systemic perfusion via its somatic channels.

General anaesthesia

Although cardiovascular monitoring is extensively used in general anaesthesia, brain oxygenation monitoring use is generally limited. NIRS monitoring can help predict cerebral desaturation events in high-risk surgeries like shoulder surgery in beach chair position,[16] thoracic surgery with one lung ventilation.[17] Its use can be extended to optimise cerebral oxygenation in patients at risk of perioperative stroke.

Neurological patients

In patients with subarachnoid haemorrhage (SAH), episodes of angiographic vasospasms were associated with 24% ± 4% rSO_2 reductions.[18] In TBI, an association has been described between rSO_2 values <60% and mortality, intracranial hypertension and compromised cerebral perfusion pressure (CPP).[19] On comparison with $SjvO_2$ and $PbtO_2$ monitoring for measuring cerebral oxygenation, rSO_2 had low accuracy for detecting moderate cerebral hypoxia ($PbtO_2$ ≤15 mmHg) and was moderately accurate for detecting severe cerebral hypoxemia ($PbtO_2$ ≤12 mmHg).[20] NIRS changes precede changes in ICP in patients having delayed traumatic haematomas.[21]

Notably, cerebral oximetry is of limited value in TBI and SAH as cerebral oedema or haemorrhage largely affects NIRS signals, and hence should be used as an additional neuromonitoring tool. However, this disadvantage has been put to use for identifying intracranial haematomas[22] and cerebral oedema.[23] It has also been found useful to detect differences in cerebral haemodynamic responses of brain-injured patients to postural changes in the neurocritical care unit.[24] NIRS has been used to test cerebral blood flow auto regulation.[25] It has been employed to determine the lower threshold limit for auto regulation during both normothermia and hypothermia and thus, might help adjusting CPP in many cardiac arrest victims.[26]

Advantages

- Non invasive
- Relatively easy to set up and use
- Lack of operator dependence
- High temporal resolution
- Can be used continuously in the intraoperative and postoperative period.

Disadvantages

- Regional monitoring technique
- Impossible to detect changes in areas located distant from the monitoring site
- Potential for contamination of signal by extracranial tissue and ambient light
- Limited spatial resolution
- Wide intra and interindividual baseline variability
- Best used as a trend monitor. Claims of the absolute threshold for cerebral ischaemia should be treated with caution.

LIMITATIONS AND CONFOUNDING FACTORS

- Presence of blood underneath the monitoring area
- Sampling volume comprises venous, capillary and arterial blood. For the cerebral cortex, average haemoglobin in tissues is distributed in proportion of 70 % venous and 30 % arterial. However, there can be significant biological variations in the blood making data interpretation difficult
- Non-haeme tissue chromophores such as melanin (hairs) or increased bilirubin in jaundice can confound rSO_2 values.

NIRS seems to be an important tool in clinician's armamentarium for predicting cerebral and somatic tissue desaturation events. Despite its potential advantages over other neuromonitoring techniques such as being user-friendly, non-invasive and measurements over multiple regions of interest simultaneously with high temporal resolution; further investigation and technological advances are necessary before it can be introduced more widely into clinical practice.

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Conflicts of interest

There are no conflicts of interest.

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