CONFERENCE PROCEEDING

Near-infrared spectroscopy—current status

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INTRODUCTION

Near-infrared spectroscopy (NIRS) is a non-invasive technique for measuring regional oxygen saturation (rsO_2). It provides real-time information of changes in rSO_2 of cerebral and somatic tissues. It can provide an early warning of decreased oxygen delivery. Tissue ischaemia is a significant contributor to increased morbidity and mortality, and thus measurement of tissue oxygenation is of paramount importance in critical care settings. In 1977, Franz Jöbsis first observed that light in the near-infrared light spectrum (wavelength 700–950 nm) can traverse biological tissue because of the relative transparency of tissue to light in this wavelength range.[1] This discovery later led to the development of NIRS technique to measure tissue oxygen saturation.

NIRS relies on 'Beer-Lambert law' (i.e., measurement of a substance concentration based on its absorption of light). Thus, measurement is based on determining haemoglobin oxygenation according to the light absorbed by haemoglobin.[2] The absorption of light is proportional to the concentration of certain chromophore molecules, mainly iron in haemoglobin and copper in cytochrome. In the brain, the primary infra-red light absorbing molecules are metal complex chromophores, namely, oxyhaemoglobin, deoxyhaemoglobin and cytochrome-C oxidase. Because about 70% of the blood in the brain is in the veins and capillaries and 25% in the arteries, most of the haemoglobin is in the venous circulation. Thus, NIRS gives a venous-weighted relative oxygen index of tissue beneath the probe.[3,4] Cerebral oximetry does not depend on pulsatility of blood flow, unlike pulse oximetry.

The NIRS sensors are applied on either side of the forehead on a clean, dirt-free, non-greasy and non-hairy part of the skin. Each NIRS sensor (optodes) has a light-emitting source and two photodetectors integrated into a self-adhesive rubber plate that is attached to the forehead. The emitter and detectors are situated 4–8 cm apart. Light is generated at specific wavelengths typically by light-emitting diodes, and is usually detected by silicon photodiodes. The light emitted from the emitter passes through the scalp, skull bone and brain tissue. The photodetectors capture the reflected light from the underlying tissue. The light detected by the photodetector close to the emitter passes through the scalp and skull bone, while the light detected by the photodetector farther from the emitter passes through the brain tissue [Figure 1]. Near field photodetection is then substracted from far field photodetection to provide a measurement of brain tissue oxygenation.

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.

There have been several attempts to determine the normal and critical value of regional cerebral oxygen saturation ($rScO_2$) However, data on cut-off values are still limited. The normal values of $rScO_2$ are reported to be 60–80% in various studies. In an animal study, a decrease of the absolute value of $rScO_2$ below 50% was associated with electroencephalogram abnormalities, and a further decrease in $rScO_2$ below 40% lead to increased brain lactate levels.[5] Absolute $rScO_2$ values below 50% have been repeatedly shown to be associated with an unfavourable clinical and/or neurological outcomes. Fischer *et al.* observed that a decrease in $rScO_2$ below 60% absolute

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was associated with an increased complication rate in patients undergoing aortic arch surgery.[6] Tang *et al*. found the incidence of post-operative cognitive dysfunction increased in patients undergoing thoracic surgery even if $rScO_2$ decreased below 65% for more than 5 min.[7] It is more appropriate to interpret the trend changes in $rScO_2$, rather than absolute values.[8] A 20% decline in $rScO_2$ from baseline is considered to be ischaemic threshold.[9,10] In general, a decrease in $rScO_2$ is reflective of an increase in oxygen extraction as a result of increased metabolism, decreased perfusion and/or stagnant perfusion. High $rScO_2$ may be indicative of increased perfusion, decreased tissue bed metabolism and/or less oxygen extraction.

CLINICAL APPLICATIONS

An important application of NIRS is for perioperative assessment of cerebral oxygenation during cardiac surgeries. It is a useful monitor in patients on cardiopulmonary bypass (CPB) where stroke and post-operative cognitive dysfunction leading to poor neurological outcome is a concern for all clinicians. The use of NIRS has been found to decrease cerebral desaturation events during CPB, fewer incidences of strokes and less post-operative major organ morbidity (mechanical ventilation, myocardial infarction).[11,12] Similarly, low $rScO_2$ levels below 50% have been associated with increased risk of post-operative cognitive dysfunction and prolonged hospital stay by about three-fold.[13,14]

NIRS has also been extensively used to monitor cerebral perfusion. It can be a valuable tool to detect cerebral ischaemia during carotid endarterectomy (CEA). Various cut-off values such as a decline of more than 20% from baseline have been recommended.[15] However, some studies recommend a decrease in $rScO_2$ of more than 12% to be reliable, sensitive and reliable specific threshold for brain ischaemia.[16]

NIRS is increasingly being used in paediatric patients during cardiac surgery, neurosurgery and critical care settings for low birth weight infants and premature children at risk of apnoea. It may also be used to measure systemic perfusion via somatic channels.

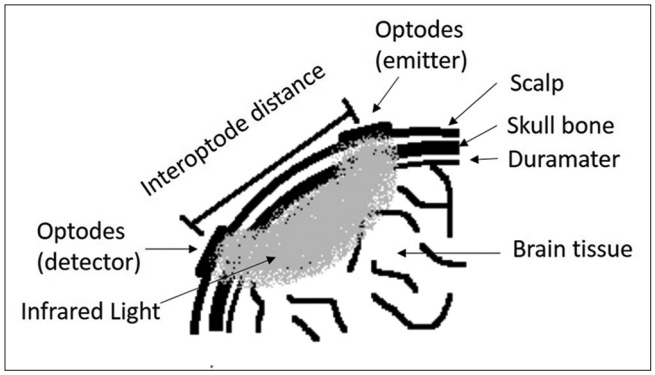

Figure 1: The placement of near-infrared spectroscopy sensors over the forehead and the path of near-infrared light from emitter to 2 detectors

NIRS monitoring can help predict cerebral desaturation events in high-risk surgeries such as shoulder surgery in beach chair position,[17] thoracic surgery with one-lung ventilation,[18] major abdominal surgery, hip surgery and laparoscopic surgeries with patients in reverse Trendelenburg position.[19] Its use can be extended to optimise cerebral oxygenation in patients at risk of perioperative stroke.

In traumatic brain injury (TBI), mortality, intracranial hypertension and compromised cerebral perfusion pressure have been found to be associated with $rScO_2$ values below 60%.[20] NIRS changes precede changes in intracranial pressure in patients having delayed traumatic haematomas.[21] NIRS has also been used to test autoregulation of cerebral blood flow (CBF).[22]

NIRS is a valuable technique for monitoring the haemodynamic changes occurring in superficial regions of the cortex.[23-25] Over the last 20 years, NIRS has become an attractive alternative to functional magnetic resonance imaging (fMRI), with several clinical advantages.[26] Besides being continuous, non-invasive and portable, NIRS is less susceptible to movement artefacts enabling long-term monitoring of the haemodynamic activity at the bedside. In patients of subarachnoid haemorrhage having cerebral vasospasm, NIRS is particularly useful in detecting changes in cortical O_2 saturation.[27] In stroke patients, studies have shown the usefulness of NIRS in detecting cerebral ischaemia.[28] Terborg *et al*. describes NIRS as non-invasive, rapid, repeatable, bedside method to detect reduction in cerebral perfusion in patients with acute ischaemic stroke without the need for transportation of critically ill patients.[29] However, the low penetration depth (upper 1 cm of the cerebral cortex) and less spatial resolution of NIRS than the resolution of standard fMRI scanners limits its sensitivity.[30]

Another application of near-infrared wave technique is the measurement of CBF. CBF measurement provides valuable information in the management of neurocritical care patients. However, currently available techniques for monitoring CBF have various limitations. The limitations include that they are invasive, do not provide continuous measurement, require exposure to ionising radiation, may require transportation of critically ill patients out of the neuro intensive care unit and expensive. Transcranial Doppler, though non-invasive, is limited to large vessel flow velocities, which do not necessarily reflect microvascular perfusion.[31] Diffuse correlation spectroscopy (DCS) is a novel non-invasive optical technique with potential to monitor bedside CBF. DCS uses near-infrared light (wavelength 650–950 nm) to

provide a continuous measurement of transcranial blood flow. Changes in blood flow are determined from DCS by measuring the decay rate of the detected light intensity autocorrelation function.[32] The integration of DCS with NIRS in a monitor that can simultaneously monitor CBF and oxy- and deoxy-haemoglobin concentrations will facilitate monitoring both CBF and oxygen metabolism in neurocritical care patients. NIRS and DSC have been used to measure tissue perfusion and oxygenation and have shown changes in autoregulation in patients of ischaemic stroke.[33] The continuous and non-invasive nature of these optical techniques may lead to new clinical tools for use in the neurocritical patients. Like NIRS, DCS is also limited by the fact that it is a measure of local CBF (flow measurements limited to the area near the surface of the cerebral cortex).

The NIRS can measure haemodynamic changes associated with functional brain activity that arises from changes in blood oxygenation and blood volume in the area of activation.

The fMRI has become the gold standard for *in vivo* imaging of the human brain. However, NIRS has also become a popular technology for studying brain function (due to being more convenient and less expensive than fMRI). Cui *et al*. demonstrated that NIRS signals are often highly correlated with fMRI measurements. Their findings suggest that, while NIRS can be an appropriate substitute for fMRI for studying brain activity related to cognitive tasks, care should be taken to ensure that the spatial resolution is adequate, and the design accounts for weaker SNR, especially in brain regions more distal from the scalp.[34]

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 being capable of taking 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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