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REVIEW

Should Cerebral Near-infrared Spectroscopy be Standard of Care in Adult Cardiac Surgery?

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Near-infrared spectroscopy (NIRS) is non-invasive, easy to use, and offers real-time monitoring of the oxygen content of cerebral tissue. An effective and user-friendly method of cerebral monitoring stands to offer a significant advance in patient care during adult cardiac surgery, particularly for surgery in which the continuity of cerebral vessels may be compromised. While the current evidence does not definitively show improvement in neurological outcomes, it can be argued that the overall risk to benefit ratio falls on the side of NIRS.

NIRS also gives information about the oxygenation of systemic tissues. It may be that in surgery that does not involve the aortic arch, the value of NIRS will be in increased individualisation of patient management and improved systemic perfusion, impacting general outcomes as much as neurological outcomes.

This review will summarise the need for neuromonitoring and the principles of NIRS. It will examine the thresholds used to define desaturation, the evidence for clinical benefit from NIRS, and the criticisms and limitations of NIRS. It will also discuss the uses of NIRS beyond improving neurological outcomes alone.

Keywords Near-infrared spectroscopy • Postoperative outcome • Brain hypoxia • Aortic arch • Cardiac surgery • Cardiopulmonary bypass

Introduction

The use of near-infrared spectroscopy (NIRS) to monitor brain protection during cardiac surgery is gaining in popularity [1], despite arguments that the evidence has failed to show definitive neurological benefits [2]. NIRS is non-invasive, easy to use, and offers real-time monitoring of the oxygen content of cerebral tissue. Some argue that there is sufficient evidence to support its use routinely [3–5], while others criticise its inherent limitations and highlight the ongoing areas of controversy surrounding its methodology [6,7].

This review will summarise the need for neuromonitoring and the principles of NIRS. It will examine the thresholds used to define desaturation, the evidence for clinical benefit from NIRS, and the criticisms and limitations of NIRS. It will also discuss the uses of NIRS beyond improving neurological outcomes alone.

The Need for Neuromonitoring in Adult Cardiac Surgery

Neurological complications are a key issue in cardiac surgery. While the safety of cardiac surgery has continued to improve over time, neurological impairment remains one of patients' particularly feared outcomes [8].

Neurological complications range from severe permanent stoke, to transient dysfunction and delerium. The two main mechanisms of neurological injury in cardiac surgery are

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embolism and hypoperfusion [9,10]. A variety of other procedural factors can contribute to the development of neurological injury, such as inflammation, systemic desaturation, and intraoperative anaemia [11]. Patient specific factors also play a key role – it has been shown in several series that 50% of patients presenting for coronary artery bypass grafting (CABG) surgery have significant extracranial carotid or intracranial artery disease [12,13]. While many factors may play a role, it is possible that hypoperfusion is the common denominator in the interaction between the multiple contributors to poor neurological outcomes [11]. Avoiding hypoperfusion could therefore significantly mitigate cerebral risk [5].

Options for Neuromonitoring

Electroencephalograph monitoring has been used in cardiac surgery since the 1950s, but has not gained widespread acceptance [14]. The reasons for this are likely to be technical difficulties in its use due to artifacts, deep anaesthesia, and brain cooling. [14] The requirement for specialised personnel increases its cost and complexity.

Transcranial Doppler has the ability to detect changes in cerebral blood flow, and can help identify cannula malposition. It also provides quantitative information about embolic load, which has been shown to be associated with cognitive outcomes [15]. However, its use is limited by several factors – it is cumbersome and operator dependent, 10% of patients cannot be assessed through the temporal window, and there is an absence of signal during times of low-flow [16,17].

Invasive jugular bulb venous oxygen saturation (SjvO2) directly measures cerebral oxygen balance. Low SjvO2 has been shown to be predictive of post-operative cognitive decline (POCD) [18]. However, this method of cerebral monitoring has also failed to gain general acceptance. Its insertion carries both a technical challenge and a risk of harm. It requires continuous blood flow past the sensor for measurements, and there are concerns that samples contain unspecified amounts of both intracranial and extracranial blood [3].

NIRS measures the regional cerebral oxygen saturation, reflecting the balance of local cerebral oxygen supply and demand [19]. Self-adhesive pads are applied to the skin of the forehead. Light is emitted in the near-infrared spectrum, and is detected by sensors at set distances from the light source. Using a modification of the Beer-Lambert law, NIRS provides a measurement of the concentration of oxygenated haemoglobin in relation to total haemoglobin concentration. Algorithms are applied to the raw data to give a measure of cerebral saturation.

Principles of Cerebral Near-infrared Spectroscopy

Jobsis first described the technique of using NIRS to measure cerebral tissue oxygenation in 1977 [20]. Light in the near-infrared wavelengths range penetrates skin and skull more readily than light at other frequencies. Near-infrared light is largely absorbed by pigmented compounds called chromophores. These chromophores include oxyhaemoglobin and deoxyhaemoglobin, along with bilirubin, lipids, melanin, and cytochrome c oxidase. Changes in light attenuation reflect changes in chromophore concentration. As the concentrations of bilirubin, lipids and melanin remain constant in an individual patient over the monitoring period, changes in light absorption are related to changes in haemoglobin, deoxyhaemoglobin and cytochrome c oxidase - the concentrations of which depend on tissue oxygenation and metabolism.

The Beer-Lambert Law describes the idealised situation where the attenuation of light between its source and a detector is due solely to absorption by chromophores. This law states that attenuation is directly proportional to three variables: chromophore concentration, the distance travelled by the light between the source and detector, and the extinction coefficient of the chromophore (which describes the absorptive properties of a chromophore at a given wavelength) [21]. By measuring the change in attenuation at two wavelengths and using the known extinction coefficients of oxyhaemoglobin and deoxyhaemoglobin at those wavelengths, the concentration change of oxyhaemoglobin and deoxyhaemoglobin can be determined [22].

In vivo, this situation is complicated by scattering of light. Some light is scattered away from the detectors and is lost, other light scatters multiple times before reaching the detector and so has a much greater path length. Light scattering is dependent on cell density and is therefore expected to remain constant over the monitoring period [22]. The Beer-Lambert law must be modified to include a multiplier to account for the increase in path length due to scattering (called the differential path length factor, calculated to be six in brain tissue) and an additive factor to account for the losses due to scattering (this amount is unknown)[22]. NIRS devices employ different techniques to overcome the difficulty due to scattering, including spatially resolved spectroscopy, frequency resolved spectroscopy, and time-resolved spectroscopy [21].

To try to eliminate light attenuation from the extracranial tissues, two detectors can be used. The signal from the closer detector (assumed to be largely extracranial attenuation) is subtracted from the detector placed further away.

All NIRS devices require an algorithm to turn the measured changes in light attenuation into a physiologic variable. Algorithms are of central importance. Studies showing the application of different algorithms to the same data yields different chromophore concentrations [23]. Comparison between devices is therefore problematic.

The vascular compartment in brain tissue is predominantly venous (70-80%), versus arterial (20-30%) [22]. Commercial cerebral oximeters assume a fixed ratio of either 70:30 or 75:25 for venous to arterial blood volume [21]. If the oxygen saturation of cerebral venous blood is about 60%, and the saturation of arterial blood is 98-100%, the average regional oxygen saturation will be 60-70%. This represents the equilibrium between the cerebral blood flow and the cerebral metabolism of oxygen [22]. Cerebral oximetry therefore gives real-time information on the balance between oxygen supply and demand [21].