REVIEW ARTICLE

CEREBRAL OXIMETRY USE FOR CARDIAC SURGERY

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Background: Studies have shown maintaining good cerebral perfusion during Cardiac Surgeries is very important in terms of patient outcomes and reducing the hospital stay, which may have its financial and clinical implications. The aim of this review study was to determine the effectiveness of Cerebral Oximetry (Transcranial Near-Infrared Spectroscopy-NIRS to monitor cerebral oxygenation) for Cardiac Surgery and to propose a possible concluding remark about its potential applications, overall clinical value and whether to keep using it or not. **Methods:** Medical database and archives including Pubmed, Embase, index medicus, index copernicus and Medline were searched. Different papers were looked upon and each had an argument, scientific evidence and background. Fifteen research papers were selected and brought under review after carefully consideration. **Results:** The papers were carefully reviewed and findings were given in favour of not using NIRS technique for Cerebral Oximetry in Cardiac Surgery. **Conclusion:** This can rightly be concluded from this study that NIRS Cerebral Oximetry does not carry the clinical significance and relevance which was previously thought. The subject under observation needs further studies and research to evaluate the effectiveness of the Cerebral Oximetry Use for Cardiac Surgery.

Keywords: NIRS; Cerebral oximetry; Cerebral perfusion

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INTRODUCTION

Maintaining adequate levels of cerebral perfusion during cardiac surgical procedures is of utmost importance in achieving positive neurologic outcomes and minimizing length of hospital stay. Since cardiac surgical interventions ranging from major aortic arch reconstruction to coronary artery bypass grafting (CABG) each carry their own inherent risk for developing perioperative strokes, transcranial near-infrared spectroscopy (NIRS) is an interesting technique that may shed light on hypo-perfusion events and decrease the overall incidence of stroke.[1,2] The use of transcranial near-infrared spectroscopy (NIRS) to monitor cerebral oxygenation levels was first developed over 3 decades ago.[3] Recent studies over the past fifteen years have created much excitement about its potential applications and overall clinical value. Although NIRS is currently being used to noninvasively measure cerebral oxygen saturation (ScO2) during many cardiac and vascular surgeries, there remain many questions about its true therapeutic value.[3] This Review Paper will offer a brief description of the NIRS technique as well as an overall assessment of current available studies highlighting the use of cerebral oximetry during cardiac surgical interventions.

MATERIAL AND METHODS

The medical archives including Pubmed, Embase, index copernicus and index medicus were searched to find out suitable articles already published and written on the relevant subject considering Cerebral Oximetry Use for Cardiac Surgery. Different papers were looked upon and each had an argument, scientific evidence and background. 15 such research papers were selected and brought under review after carefully considering them.

DISCUSSION

Cerebral complications associated with cardiac surgery:

Adequate cerebral perfusion is necessary to maintain proper oxygenation and meet aerobic metabolic demands.[1] However, brain ischemia associated with cardiac surgical intervention can have many aetiologies and can be hard to identify.[1,3] While cerebral emboli is a major cause of perioperative strokes, more serious consideration is being placed on the influence of cerebral hypo-perfusion resulting in perioperative neurologic damage as a result of decreased clearance of micro-emboli and ischemia to the brain.[2,4] Although the direct cause of hypo-perfusion may not be immediately evident, it may be the result of a single or multifactorial source consisting of cerebrovascular disease, inadvertent cannula malposition, hyperventilation resulting in cerebral vasoconstriction, cerebral venous outflow obstruction, inadequate perfusion pressure, or anaemia.[2,5]

Based on the source of insult, there are two main forms of postoperative damage that may occur after cardiac surgeries: neurological dysfunction (ND) and neurocognitive dysfunction (NCD).[6] Neurologic dysfunction is much easier to recognize as it is categorized as a clinically evident stroke, hypoxic encephalopathy, transient ischemic attack, or stupor.[6] Although more subtle and not as clinically evident, neurocognitive dysfunction is the more common of the two and is defined as postoperative confusion, agitation, delirium, prolonged obtundation, or transient Parkinsonism.[6] The incidence of emboli related neurologic damage can be mitigated, although not completely removed, with blood thinners, avoidance of highly calcified vasculature, and good surgical technique.[6,7] However, strategies to manage hypo-perfusion require accurate, real time monitoring of cerebral tissue perfusion. Similar to pulse oximetry, the theory behind cerebral oximetry is that it offers a means to detect and quantify cerebral oxygenation in a non-invasive manner, allowing the opportunity for immediate intervention, resolution, and potentially diminished incidence of neurologic damage.[1–4,8]

Technical background:

The absorption of energy within the near-infrared region of the electromagnetic spectrum differs for haemoglobin depending on its oxygenation status.[1,4,8] Oxygenated haemoglobin (HbO) absorbs light within the spectrum of 850–1000 nm whereas deoxygenated haemoglobin (HbO_d) absorbs light within the spectrum of 600–750 nm.[8] NIRS exploits this difference in absorption spectra in order to estimate oxygen delivery and consumption within grey matter of the cerebral cortex so that it can be adjusted as necessary to maintain proper perfusion.[1]

A light source containing only two wavelengths of light, 730 nm and 810 nm, is placed on the skin overlaying the patient's frontal-temporal region in order to read the oxygen saturation of the watershed area between the anterior cerebral artery and the middle cerebral artery.[1,4] This light is transmitted through the patient's scalp and skull, partially absorbed and partially reflected in a hyperbolic pattern by the target tissue and then detected by two detectors located 3 cm and 4 cm lateral to the source of light.[4,9,10] An algorithm, based on the assumption that the ratio of arterial to venous blood in the gas exchanging cerebral venules is somewhere between a 15:85 ratio and a 25:75 ratio, estimates the percent of each spectra that was absorbed by haemoglobin in order to determine the percent saturation of haemoglobin.[3,4]

Current guidelines suggest that baseline regional oxygen saturation (rSO2) should be obtained for each patient preoperatively. For patients whose baseline rSO2 is greater than 50%, any reduction in rSO2 of 20% from that baseline requires intervention, while patients with a baseline rSO2 less than 50% require intervention with any reduction in rSO2 of 15%.[11] Although there is evidence suggesting that adhering to this protocol does benefit postoperative outcomes, its reliability remains in question and a more personalized, tailored approach needs to be developed.[7,12] It appears that there are some patients who could tolerate greater reductions in rSO2 than the guidelines suggest without incurring neurologic damage, while other patient populations require quicker intervention before defined reductions in rSO2 are reached. Further studies targeted at identifying variables that define these subgroups would be beneficial since there are inherent risks for both premature and delayed interventions.[12]

Limitations of NIRS:

In spite of the benefits that cerebral oximetry may offer, there are a number of limitations which hinder its implementation as a valuable monitoring technique. Because the positions of the probes define exactly where measurements of cerebral oxygenation originate from, oxygen saturation readings can be easily altered or attenuated based on the patient's skull contour or presence of skull defects.[4] This place a greater emphasis on the precise application of the probes and detectors, increasing the incidence for human error and erroneous readings. It is estimated that NIRS only attains readings from approximately 1 cc of cerebral tissue and is currently only being used to monitor oxygenation levels within the watershed area of the frontal lobe.[2] With such a limited area of application, no information is being gathered about perfusion to the rest of the brain and brainstem, essentially making this technique useless in the event that an embolism or hypo-perfusion develop in alternative parts of the brain.[2]

In order to validate NIRS as a reliable monitoring technique, we must evaluate its accuracy and consistency in terms of quantifying cerebral tissue oxygenation. NIRS is limited by the fact that it can only calculate the HbO relative to total haemoglobin (Hb_t), instead of quantifying Hb_t.[3] Additionally, intravascular oxygenation may not completely correlate with intracellular oxygenation while signal contamination must also be taken into consideration.[3] Extracerebral tissues including skin and hair can absorb a large enough percentage of the emitted light to cause a low signal return to the sensors.[2,4] Although very minimal, molecules other than haemoglobin that share the same optical properties such as skin pigments and myoglobin may erroneously mimic oxy- or deoxy-haemoglobin and cause inaccurate measurements.[1]

Although the limitations of cerebral oximetry do not appear to outweigh its benefits alone, the significant cost of single-use patient sensors may be deemed too expensive.[4] However, some investigators hypothesize that the cost of using cerebral oximetry is justified and compensated for by improved postoperative patient outcomes and reduced hospital stays. A preliminary study of 100 patients receiving NIRS monitoring during routine CABG compared to a control group receiving no monitoring has found that after accounting for the cost of INVOS equipment, savings based on reduced lengths of hospital stays for patients amounted to about £1,020 per patient.[13] Alone 158 008 CABG procedure were documented in 2010.[14]

However, it must be noted that larger, randomized trials are necessary to notice a true trend in this regard, especially in light of the levels of disagreement among investigators. Overall, further technological and diagnostic advances should be sought to correct and alleviate the technical shortcomings associated with cerebral oximetry use in order to better predict patient outcomes and enhance its cost/benefit ratio.

NIRS Application in cardiac surgery

Randomized, Prospective Studies:

Our literature search identified two prospective, randomized trials that evaluate the efficacy of perioperative interventions to correct cerebral desaturation on the basis of NIRS rSO2 monitoring during cardiac surgery. The first study was published in 2007 by Murkin *et al*[15] and reported that monitoring cerebral rSO2 levels during coronary artery bypass surgery with proper intervention reduces the incidence of profound cerebral desaturation and is associated with less major organ dysfunction. This study was based on 200 patients (100 control and 100 intervention) undergoing CABG, with a predetermined order of intraoperative interventions occurring when rSO2 values fell below 75% of preoperative baseline values for greater than 15s. Intervention to correct cerebral desaturation was successful 80.4% of the time, with 56 out of 100 patients requiring intervention, 40 of which required 3 or more interventions.

The majority of findings was not statistically significant and included the incidence of MI, stroke, ventilation time, and overall LOS. The study aimed to demonstrate a 50% decrease in the overall incidence of complications with intervention, but found that the actual rate of complications was 30% in the control group with a non-statistically significant reduction to 23% in the intervention group. A subsequent retrospective analysis termed Major Organ Morbidity and Mortality (MOMM), defined as the incidence of stroke, renal failure requiring dialysis, prolonged ventilation >48h, deep sternal infection, reoperation, and death, presented significant results between groups (10 control vs 2 intervention) and correlated to longer ICU LOS and overall LOS in comparison to patients with no MOMM. Although statistically significant, MOMM was not the intended focus of the study and was retrospectively applied to the acquired data and became a major focus of the study outcomes. Additional limitations include a lack of assessment of postoperative neurocognitive functions preventing correlations to be made between cerebral desaturation and subclinical neurologic damage, as well as a loss of data for 3% of patients (4 controls and 2 interventions).

The second randomized prospective study was published in 2009 by Slater *et al*[16] and concluded that prolonged intraoperative desaturation was significantly associated with early postoperative cognitive decline and an increased LOS. The study included 240 patients (115 control and 125 intervention) undergoing CABG, with the order of perioperative interventions being chosen at the anaesthesiologist's discretion if rSO2 values fell below 20% of preoperative baseline values. Cognitive decline was assessed using neuropsychological tests including the presence or absence of visual disturbance, aphasia, paralysis or weakness, and mental status evaluation. No significant difference was found between the incidence of cerebral desaturation (30% control vs 26% intervention), nor for the occurrence of cognitive decline (61% control vs 58% intervention). Although there was no correlation between rSO2 desaturation scores and late cognitive decline at a time point of 3 months, statistically significant correlations were identified between prolonged desaturation and early postoperative decline. In addition, patients with a prolonged rSO2 desaturation correlated with a LOS greater than 6 days. A limitation of the study that had the potential to alter outcomes was the lack of a structured and predetermined intervention protocol. The introduction of choice has the potential to allow for bias and skewed results, and a well-defined protocol would allow for a fairer assessment of outcomes.

Cohort Studies:

Two nonrandomized, retrospective studies were found. The first study was published by Goldman *et al*[17] in 2004 and concluded that there was no significant change in the incidence of stroke and transient ischemic attacks with the implementation of cerebral oximetry. However, there was a significant reduction in permanent strokes, total ventilator time, and the proportion of patients requiring prolonged ventilation among the intervention group. Comparisons were made for all cardiac surgeries between a control group of 1,034 patients (July 1, 2000 to December 31, 2001) and an intervention group of 1,245 patients (January 1, 2002 to June 30, 2003). NIRS monitoring was used for the 18-month duration to maintain cerebral oximetry values at or near preoperative baseline values using predefined intervention protocols. Patients were grouped based on NYHA classifications, with the mean NYHA level being higher in the intervention group, which may explain why the use of NIRS monitoring failed to mitigate the incidence of stroke. Additionally, there was no standard of care to guarantee that every patient's rSO2 values were maintained at or near preoperative baseline values.

The second cohort study was published in 2012 by Palmbergen *et al*[18] and assessed the use of preoperative transcranial Doppler (TCD) and perioperative NIRS to identify areas of poor haemodynamic and hypo-perfusion to decrease the rate of postoperative delirium (POD). When examining CABG and CABG plus procedures, there was a significant decrease in the POD rate, but no significant change in ICU LOS. The control group consisted of 233 patients from 2009 that received standard preoperative screenings, while the intervention group consisted of 409 patients from 2010 whose preoperative screening included the newly developed Haga Brain Care Strategy (HBCS) which implemented the use of TCD and NIRS. Intervention was initiated when cerebral perfusion dropped below 20% of preoperative baseline values and resulted in a decrease in POD from 13.3% in 2009 to 7.3% in 2010 (p=0.019), but no significant change in average ICU LOS, going from 2.11 days in 2009 to 1.83 days in 2010 (p=0.228).

Although the new HBCS improved POD rate, there is no way to confidently attribute the decrease in delirium rate to either the use of TCD or NIRS. Not every patient in 2010 received TCD, NIRS, or both, with only 49.1% of patients receiving NIRS monitoring, and 34.0% receiving both. In addition, without a set protocol, intervention was dependent on anaesthesiologist discretion allowing for bias and human error. The author also states that simply the awareness among anesthesiologists about the importance of maintaining adequate cerebral blood flow in addition to preserving blood pressure may have contributed to the decline in POD rate among intervention patients.

CONCLUSION

In spite of its benefits, the NIRS technique used to monitor cerebral oxygenation has its shortcomings which hinder its implementation as a valuable monitoring technique. The limited area of application for NIRS to monitor oxygen levels from only the 1cc watershed area of frontal lobe makes it a useless technique, especially in the event of hypo-perfusion or embolism in other parts of the brain. Moreover, NIRS does not quantify the Hbt levels and is a mere estimate of HbO% relative to Hb_t. It's not just the limitations of the NIRS technique which outweigh its benefits but the significant cost it adds to a single procedure which can be of significance specially for the 3rd world countries where there is no concept of insurance. After careful review of medical literature, Research papers and scientific evidence audited in these papers, it can rightly be concluded from this study that NIRS technique for Cerebral Oximetry does not carry the clinical significance and relevance which was previously thought. The subject under observation needs further studies and research to evaluate the effectiveness of the Cerebral Oximetry use for cardiac surgery.

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