REVIEW ARTICLE

Cerebral Oximetry Monitoring in Cardiac Surgery: A Technology for Non-invasive Brain Monitoring

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ABSTRACT

Brain injury is a common complication in cardiac surgery. Cerebral oximetry has been shown to reduce major organ dysfunction resulted by cardiac surgery. Monitoring of cerebral perfusion during cardiac surgery is needed to reduce neurological complications. The technology of near-infrared spectroscopy (NIRS) to assess cerebral oxygenation levels was introduced 40 years ago and have been used clinically for over 20 years. Non-invasive cerebral oximetry uses transcranial near-infrared spectroscopy to measure oxygen saturation within a small area of the cerebral cortical vasculature. Oximeters are instruments that use the absorption of light to measure the concentration of different types of hemoglobin. These devices are widely used in various units as a guide to therapeutic interventions to indicate the oxygenation status of patients. Cerebral oximetry is a non-invasive tool for continuous monitoring of cerebral perfusion. However, in different conditions, this technology may show the degree of oxygen saturation as false, high or low. Although pulse oximeters are useful tools for monitoring patient oxygenation, there have been few studies on the accuracy and precision of pulse oximeter in specific clinical conditions and in the intensive care unit. On the other hand, cerebral oxygenation monitoring using near infrared spectroscopy detects changes in oxygenation earlier than pulse oximetry. This review was performed to describe current information on cerebral oximetric monitoring in cardiac surgery and its effect on cardiovascular surgery outcome as well as the factors which have restricted its more widespread application. Because oxygen saturation monitoring by NIRS and using the brain as an index organ for perfusion in cardiac surgery has been associated with fewer incidences of major organ dysfunction and shorter duration in the intensive care unit.
Keywords: Brain Monitoring, Cardiac Surgery, Cerebral Oximetry

INTRODUCTION

Brain injury is a usual complication following cardiac surgery and is defined by postoperative neurocognitive decline and frank stroke, with rates as 50% and 3%, respectively[1]. Literature showed that manifestations of brain injury may be diagnosed in a disturbingly large number of cases who undergo cardiovascular surgery. A study revealed a 6.2% incidence of serious neurological injury after myocardial revascularization[2]. Therefore, it is important to measure the oxygen saturation of arterial blood and, consequently, to estimate the oxygen pressure of patients' arterial blood. Previous studies recommended to use of an emerging technology to identify and correct a potentially injurious regional cerebral microcirculatory perfusion imbalance during cardiovascular surgery[(3-5)]. Studies have shown that the use of continuous pulse oximetry monitoring reduces the likelihood of hypoxia[(5,6)]. The potential use of cerebral oximetry technology to monitor cerebral oxygen balance was first introduced by Jobsis in 1977[7]. Cerebral oximetry is a method of monitoring continuous cerebral tissue oxygen saturation[8]. This technique uses NIRS to measure oxygen saturation within a small region of the cerebral cortical vasculature and has already been used during various surgical operations such as cardiac surgery[9]. NIRS has been used extensively over the past years as a continuous monitor of the balance between cerebral oxygen delivery and consumption.

Cardiac surgery patients with decreased cerebral oxygen saturation rather than baseline values have been shown an increase in overall major organ dysfunction[10]. An extensive study reported that serious neurological deficits occur in up to 6.2% of patients after myocardial re-vascularization. Another study shows that more than 40% of patients undergoing cardiac surgery develop functional impairment due to persistent cognitive decline[2,11]. Near-infrared spectroscopy (NIRS) provides a noninvasive and continuous monitoring of regional cerebral oxygen saturation[12,13]. Cerebral injury caused by cardiac surgery has long-lasting consequences that occurs in various forms and often has significant impact on the patient's quality of life following surgery. Literature review have revealed that the monitoring of regional cerebral oxygen saturation provides an opportunity for early detection of the imbalance between cerebral oxygen demand and supply to avoid complications[10,13].

Overall cerebral oxygen saturation monitoring by Near-infrared spectroscopy as well as using the brain as an index organ for perfusion in cardiac surgery has been associated with decreased incidences of major organ dysfunction[10]. Therefore, our goals in this paper are to provide a brief overview of describe current information on cerebral oximetric monitoring in cardiac surgery, and its effect on cardiovascular surgery as well as the factors which have restricted its more widespread use. We performed the literature review within the PubMed database using the keywords: "Brain Monitoring, Cardiac Surgery, Cerebral Oximetry" with dates from 2000 to 2019. This paper begins by describing the technical considerations of cerebral monitoring and comparison of cerebral oximetry and pulse oximetry. We then provide an overview on the monitoring of cerebral oxygen saturation by near-infrared spectroscopy and causes of brain injury.

Technical considerations of cerebral monitoring: Near-infrared spectroscopy (Cerebral oximetry: a means to monitor regional cerebral perfusion) is a non-invasive optical technology to continuous assessment of microcirculatory oxygenation[14,15]. NIRS has a light source of two known wavelengths that relies on the relative transparency of biological tissues to near-infrared light (700– 900nm) where oxygenated and deoxygenated hemoglobin have distinct absorption spectra[16]. Optical bundles transmit light from the source to the tissue and this is then detected by a light detector[17]. By measuring the attenuation of light at several wavelengths and distances between emitter and detector, it is possible to determine a value for cerebral oxygen saturation[18]. The computer program will then process the information with an algorithm to give a reading for the cerebral oxygenation[19,20].

The probe is usually placed on the skin overlying the frontal-temporal region as suggested by the manufacturer[17]. To avoid signal contamination optimum contact with the skin is essential. Ensure to maximal skin contact can be achieved by avoiding areas with hair. Reported that light absorption by the hair follicles even after shaving may lead to a very low return of signals[21]. Wrong sensor location or a poorly applied sensor with inadequate skin contact may result in the emitter's light reaching the detector without passing through blood-perfused tissues that may result in physio-optic dissociation with the light being shunted externally or within the tissue[22]. Here it is assumption that light in the near infrared range penetrates in the skin, skull, and deeper cerebral tissues readily[20]. Oxygenated Hb absorbs less red and more infrared than deoxygenated Hb[19,22]. A commonly accepted normal value for regional hemoglobin oxygen saturation has not been reported[24].

An index equal of 67±10 has been established for regional hemoglobin oxygen saturation to conscious healthy volunteers and cardiac patients[3]. Previous studies stated that a reduction equal of 20% in regional hemoglobin oxygen saturation index from the baseline value is an indication of cerebral oxygenation imbalance and the need for intervention[(3)]. Baseline cerebral oximetry values should be achieved before induction of anesthesia (normal values range from 60% - 80%). Although lower values of 55% are not considered abnormal in some cardiac patients[25]. Adequate cerebral oxygenation is related to adequate cerebral blood flow and oxygen content. Factors affecting either of these will result in a reduction in cerebral oxygenation and reduce in cerebral oximetry values. Some factors that may result in reduction of cerebral oxygenation values caused by alterations in blood flow or oxygen content are presented in table 1.

Table 1: Factors affecting reduced cerebral oxygenation values (26)

Cerebral blood flow	Oxygen content
Arterial inflow/venous outflow obstruction	Inspired oxygen concentration
Cardiac output	Pulmonary function
Major hemorrhage	Hemoglobin concentration
Acid–base status	Hemoglobin saturation

Cerebral oximetry vs. pulse oximetry: Although both of cerebral oximetry and pulse oximetry use near infrared light signals, however there are several differences between them. Cerebral oximetry monitors the non-pulsatile signal component reflecting tissue circulation such as arterioles and venules, whereas pulse oximetry monitors the pulsatile signal component reflecting arterial circulation[16]. The pulse oximeter converts the optical transducer signals into physiological information. Pulse oximeters are able to show the degree of oxygen saturation continuously and non-invasively. Therefore, cerebral oximetry is a tool to monitor regional cerebral perfusion that was developed as a non-invasive technology, similar to pulse oximetry, for continuous assessment of cerebral blood flow. The differences of cerebral oximetry and pulse oximetry are presented in table 2.

Table 2: Pulse oximetry vs. cerebral oximetry* (17)

Oximetry	Pulsatility	Light transmission	Wave length	Arterial component	Oxygen saturation	Validation	Limitation	LED
Pulse	Pulsatile	Transmission	660/940nm	Mainly arterial	Hb (arterial)	In volunteers	Diathermy	1 Emitter/1 sensor
Cerebral	Non-pulsatile	Reflectance	730/810nm	25% Arterial:75% venous	Cerebral venous saturation	In volunteers	Diathermy	1 Emitter/2 sensors

*Hb= denotes hemoglobin; LED= light emitting diode

Beneficial effects and helpful information of cerebral oximetry: Neurologic injuries of perioperative are a devastating complication that are not always predictable, but contributes to significant morbidity and mortality. Since adverse cerebral outcomes still remain a major cause of morbidity, there is a need for monitoring adequacy of cerebral perfusion during cardiac surgery to reduce neurological complications. Cerebral oximetry using near infrared spectroscopy has gained attraction in contemporary practice as a monitor of brain perfusion during cardiac surgery. Cerebral perfusion is a main factor to regional and global imbalance in oxygen demand/ supply, which may cause brain injury following cardiac surgery. Cerebral oximetry was developed as a non-invasive technology, similar to pulse oximetry, as means to monitor regional cerebral perfusion for the continuous assessment of cerebral blood flow. Previous studies have demonstrated that the use of cerebral oximetry reduces both postoperative cognitive impairment and the length of hospital stay[17].

Open heart surgery first performed by Gibbon in 1953 and then has become increasingly common[17]. Cerebral injury following cardiac surgery is a dreaded outcome and is associated with longer intensive care unit stays and increased mortality[27]. Ahonen and Salmenpera (2004) found that the incidence of cerebral complications following cardiac surgery is age-related[23] as the incidence of stroke after coronary artery bypass graft surgery increased from less than 1% in patients under 64 years old up to 7 to 9% in patients older than 75 years. Brain injury after cardiac surgery is usually attributed to two main causes: embolization and compromised cerebral blood flow, although systemic inflammatory response has also been implicated[28]. These Embolization as a major cause of neurological injury after cardiac surgery could be from aortic Atheroma, platelet-fibrin and leukocyte aggregates as well as bubbles from the cardiopulmonary circuit or surgical field[28]. Another main cause of brain injury is hypoperfusion that occurs during cardiac surgery. The pressure of cerebral perfusion is usually kept above 50 mm Hg during coronary artery bypass graft surgery to avoid neurological injury as intra-operative hypotension has been associated with hypoxic-ischemic brain injury[29]. In a literature review stated that there was a three-fold increase in the occurrence of cerebral complications when mean arterial pressure fell below 40 mm Hg than if it was maintained above 60mmHg. Authors found that the risk of postoperative neurological complications will be four-fold when systolic blood pressures fell below 50 mm Hg for 10 minutes or longer[30].

Although previous clinical trials showed that cerebral desaturation may exhibition neurocognitive dysfunction following cardiac surgery and directing therapy to treatment of these desaturation is effective[31,32] but an extensive meta-analysis failed to show any outcome benefit after cardiac surgery due to monitoring and management by cerebral oximetry[33]. In a study by Negargar et al. (2007) to investigation of the relationship between cerebral oxygen saturation changes and postoperative neurologic complications, seventy-two adult patients with ASA class II, III who were scheduled for elective cardiac surgery[34]. Patients were randomized into three groups: Group I: with CPB (on –pump) Group II: without CPB (off- pump) Group III: valve surgery. In this study neuropsychological outcome was assessed by the Mini-Mental State Examination. Cerebral oxygen saturation was also measured. The results of this study revealed that there was not a significant relationship between cerebral oxygen desaturation and neurologic complications. However, patients who had neurologic complications showed cerebral oxygen desaturation and none of the patients who had normal cerebral oxygen saturation during operation, showed neurologic complications. They believe that considering small numbers of microembolies which either are absorbed or cause only subclinical brain injury, use of cerebral oximetry may be useful. Overall, authors reported although cerebral oximetry is a non-invasive and useful method of monitoring during cardiac surgery, it has low accuracy to determine postoperative neurologic complications.

Table 3: Studies on cerebral oximetry in anesthesia for cardiac and non-cardiac surgery

First author(year)	Title	Main points	Reference
Frogel (2019)	The Value of Cerebral Oximetry Monitoring in Cardiac Surgery: Challenges and Solutions in Adult and Pediatric Practice	Probably the clinical application of this technology will expand significantly in the foreseeable future.	(35)
Green (2017)	Cerebral oximetry and its role in adult cardiac, non-cardiac surgery and resuscitation from cardiac arrest	There is probably a long way to go before cerebral oximetry can be regarded as standard monitoring, even in some of the specialized surgical procedures.	(36)
Deschamps (2016)	Cerebral Oximetry Monitoring to Maintain Normal Cerebral Oxygen Saturation during High-risk Cardiac Surgery	Study sites were successful in reversal of desaturation, randomization, and follow-up in cardiac surgery, supporting the feasibility of conducting a multicenter randomized controlled trial.	(32)
Sanfilippo (2015)	Cerebral oximetry and return of spontaneous circulation after cardiac arrest: …	Higher initial and average regional cerebral oxygen saturation values are both associated with greater chances of achieving return of spontaneous circulation in patients suffering of cardiac arrest.	(37)
Nielsen (2014)	Systematic review of NIRS determined cerebral oxygenation in non-cardiac surgery	It is need to be established evidence for an association between cerebral desaturation with postoperative outcome parameters other than cognitive dysfunction.	(38)
Mohandas (2013)	Impact of monitoring cerebral oxygen saturation on the outcome of patients undergoing open heart surgery	Monitoring of regional cerebral oxygen saturation during cardiopulmonary bypass can significantly decrease the incidence of postoperative neurocognitive decline.	(39)
Zheng (2013)	Cerebral NIRS monitoring and neurological outcomes in adult cardiac surgery	Reductions in regional cerebral O2 saturation in cardiac surgery may identify cardiopulmonary bypass cannula malposition, particularly during aortic surgery.	(40)
Table 3. Studies on cerebral oximetry in anesthesia for cardiac and non-cardiac surgery- Continued			
Scheeren (2012)	Monitoring tissue oxygenation by NIRS: background and current application	NIRS monitoring may be used to detect tissue hypoxia in emergency settings, where it has prognostic significance and enables monitoring of therapeutic interventions.	(41)
Baikoussis (2010)	Baseline cerebral oximetry values in cardiac and vascular surgery patients	Compared to cardiac surgery, carotid endarterectomy patients are older, and have higher baseline INVOS values and greater stroke frequency.	(42)
Fischer (2008)	Recent advances in application of cerebral oximetry in adult cardiovascular surgery	Complementary to the arterial oxygen saturation measured via pulse oximetry, cerebral tissue oxygen saturation reflects the balance of local cerebral oxygen supply-demand.	(43)
Negargar (2007)	The relationship between cerebral oxygen saturation changes and post-operative neurologic complication in patients undergoing cardiac surgery	Although cerebral oximetry is a useful and non-invasive method to monitoring in cardiac surgery, it has low accuracy to determine the postoperative neurologic complications. In this clinical trial, there was not a statistically significant relationship between cerebral oxygen desaturation and neurologic complications However patients who had neurologic complications showed cerebral oxygen desaturation and none of the patients who had normal cerebral oxygen saturation during operation, showed neurologic complication.	(34)
Tortoriello (2005)	A noninvasive estimation of mixed venous oxygen saturation using near-infrared spectroscopy by cerebral oximetry in pediatric cardiac surgery patients	It is not possible to predict absolute values of mixed venous oxygen saturation for any given patient based solely on the noninvasive measurement of cerebral regional cerebral oxygen saturation.	(16)
Edmonds (2004)	Cerebral Oximetry for Cardiac and Vascular Surgery	Cerebral oximetry provides the only non-invasive means to continually monitoring brain oxygen imbalance and guiding interventions aimed at its correction.	(3)

CONCLUSION

Stroke as a brain injury following cardiac surgery is associated with up to 10 times increase in mortality, and the many of patients who suffer a stroke require extensive rehabilitation[44]. Thus, there is a need for monitoring of cerebral perfusion during cardiac surgery to reduce neurological complications. Cerebral perfusion is a major factor for regional and global imbalance in oxygen supply/demand which may result in brain injury following cardiac surgery. According to the literature review the cerebral oximetry should be a common monitor during cardiac surgery.

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