NIH Public Access
Author Manuscript
Best Pract Res Clin Anaesthesiol. Author manuscript; available in PMC 2015 December 01.

Published in final edited form as:
Best Pract Res Clin Anaesthesiol. 2014 December ; 28(4): 429–439. doi:10.1016/j.bpa.2014.09.002.

Cerebral and Tissue Oximetry

Jochen Steppan, MD and **Charles W. Hogue Jr, MD**
Department of Anesthesiology and Critical Care Medicine, The Johns Hopkins Medical Institutions, Baltimore, MD

Abstract

The use of near-infrared spectroscopy (NIRS) has been increasingly adopted in cardiac surgery to measure regional cerebral oxygen saturation. This method takes advantage of the fact that light in the near-infrared spectrum penetrates tissue, including bone and muscle. Sensors are placed at fixed distances from a light emitter, and algorithms subtract superficial light absorption from deep absorption to provide an index of tissue oxygenation. Although the popularity of NIRS monitoring is growing, definitive data that prove outcome benefits with its use remain sparse. Therefore, widespread, routine use of NIRS as a standard-of-care monitor cannot be recommended at present. Recent investigations have focused on the use of NIRS in subgroups that may benefit from NIRS monitoring, such as pediatric patients. Furthermore, a novel application of processed NIRS information for monitoring cerebral autoregulation and tissue oxygenation (e.g., kidneys and the gut) is promising.

Keywords

Near-infrared spectroscopy; NIRS; cerebral autoregulation; cardiac surgery; anesthesia; monitor

Background

The principal discoveries that underlie the monitoring of regional cerebral oximetry ($rScO_2$) include those by Jöbsis in the late 1970s and the theoretical framework by Norris before [1, 2]. He demonstrated that light in the near-infrared spectrum penetrates tissue, including bone and muscle, and that certain chromophores (e.g., cytochrome oxidase C) absorb light in this spectrum. In 1985, Ferrari and colleagues demonstrated that light emitted at the wavelength specific for the peak absorption of the chromophores oxyhemoglobin (920 nm) and total hemoglobin (760 nm) can be used to measure brain oxygenation in humans (Figure 1A) [3]. Cerebral oximetry has since gained widespread popularity, especially in adult and pediatric

© 2014 Elsevier Ltd. All rights reserved.

Corresponding Author: Charles W. Hogue, Jr., MD, Department of Anesthesiology and Critical Care Medicine, The Johns Hopkins University School of Medicine, 1800 Orleans St., Baltimore, MD 21287, Telephone: 410-614-1516, Fax: 410-955-0994, chogue2@jhmi.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Conflict of interest
Jochen Steppan: none

NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

cardiac surgery [4, 5]. Today, physicians can choose from a wide variety of devices for monitoring $rScO_2$, including INVOS™ (Somanetics/Covidien, Inc., Boulder, CO), FORESIGHT ™ (CAS Medical Systems, Branford, CN), EQUANOX™ (Nonin Medical Inc., Plymouth, MN), CerOx™ (Ornim Medical, Lod, Israel), NIRO™ (Hamamatsu Photonics, Hamamatsu City, Japan), and TOS-96™ (Tostec, Tokyo, Japan). Now, these methods are also being used to monitor oxygenation in other tissue beds, such as extremities distal to the site of arterial cannulation during intra-aortic balloon counter-pulsation or cardiopulmonary bypass (CPB). Newer applications of cerebral oximetry include its use as a surrogate for cerebral blood flow (CBF) for bedside monitoring of autoregulation [6] and regional tissue perfusion [7]. Monitoring $rScO_2$ and tissue oxygenation may provide important clinical data on the balance between tissue oxygen supply and demand in near real-time, allowing for therapeutic interventions to prevent tissue ischemic injury [8]. However, despite a multitude of anecdotal reports, recent reviews have tempered the enthusiasm for routine use of $rScO_2$ by questioning whether it leads to improved patient outcomes [8, 9]. This review will describe the basic principle of $rScO_2$ and tissue oximetry; the general considerations and limitations for its use; its clinical applications in cardiac, carotid artery, and pediatric surgery; and emerging applications.

Basic Principle

An understanding of the physical principles of cerebral and tissue oximetry is important for the clinician to interpret oximetry results and appreciate its limitations. Several comprehensive reviews of this technology are available [8, 10, 11]. Oximetry is based on the transmission of light in the near-infrared spectrum across tissue and its absorption by chromophores (Figure 1A). For cerebral oximetry, self-adhesive emitter / sensor pads applied to the skin of the forehead measure light attenuation noninvasively at a set distance from a NIRS-emitting light source. The absorption of the emitted light is directly proportional to chromophore concentration, the absorption coefficient of the chromophore, and the distance that the light travels between the emitting source and the detector, as stated in the Beer-Lambert law [12]. A modification of the Beer-Lambert law can be expressed as follows:

$$[X]=\frac{\Delta A}{L \times \varepsilon}$$

where [X] is the chromophore concentration, ΔA is light attenuation, L is the length that the light traveled, and ε is the chromophore extinction coefficient. Chromophore concentration can thereby be calculated by measuring light attenuation between the detector and the source distance and using a previously determined extinction coefficient [13]. An approach to determine $rScO_2$ utilizes the distinct absorption spectra of oxyhemoglobin and deoxyhemoglobin, which are maximally separated at 700 and 850 nm (Figure 1B). At a minimum, two wavelengths of light are needed to measure the relative concentration of two chromophores. The concentration of oxyhemoglobin can be measured as the ratio of light absorbed for oxyhemoglobin compared with light absorbed for total hemoglobin. However, the distance between the emitting light source and the detector cannot be measured directly, given the refraction, reflection, and scattering of the photons in biological tissue. Therefore,

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

only relative changes in oxygen saturation can be measured [14]. To overcome this limitation, device manufacturers use 1) computer modeling and simulation to estimate the distance traveled by the emitted light; 2) multi-distance spectroscopy [15]; 3) time-resolved spectroscopy with a laser light [16]; or 4) multiple near-infrared wavelengths with frequency domain analysis to determine a tissue absorption coefficient [17]. The latter two techniques obviate the need to know the actual distance traveled by light [18]. Given the many clinical devices available, manufacturers use different proprietary algorithms that are optimized to the specific device, as previously reviewed [19]. Importantly, one should keep in mind that because of the number and variability of these algorithms, oxygen saturation values can differ when measured by devices from different manufacturers [20]. These devices also use different algorithms to subtract NIRS absorption in superficial tissue (1 cm) from that in deeper tissue (2 cm) to yield oxygen saturation in the superficial frontal cortex [21].

General Considerations and Limitations

Unlike pulse oximetry, NIRS-based cerebral and tissue oximeters do not include plethysmography and, thus, do not differentiate between arterial and venous blood. Therefore cerebral and tissue oximeters do not provide an indicator of oxygen delivery but rather provide information on balance between regional oxygen supply and demand [22]. The absence of plethysmography has advantages insofar as measurements are provided even in the absence of a pulse, such as during CPB. However, a limitation with this technology is the possibility that one could erroneously measure the oxygenation state of tissue unrelated to the targeted organ perfusion (e.g., extra-cerebral tissue when measuring $rScO_2$). This potential error can be overcome by using the spatial resolution of the system (photon penetration is about one third the distance between receiver and transmitter). By adding detectors at multiple distances from the emitted light source, specific algorithms can subtract the absorption signal of superficial tissue (detected with sensors closest to the light transmitter) from the absorption signal received from deeper tissues (the more distant receivers). Moreover, because of variability in the exact composition of arteries, veins, capillaries, and nonvascular tissue penetrated [23], baseline values vary between subjects by approximately 10% [20], making it more appropriate to use cerebral and tissue oximetry as a trend monitor rather than as an absolute index of tissue oxygenation. These devises usually assume a relative and fixed amount of arterial versus venous blood (e.g. 30:70) to calculate oxygen saturation. However the relative concentrations of arterial versus venous blood in the area measured can very significantly between and within subjects, especially with changes in partial pressure of carbon dioxide [24]. Acute changes in the distribution of hemoglobin between the arterial and venous system (e.g., opening of arterio-venous shunts, hematoma formation, and hemodilution) or changes in the distance between the sensor and light source (e.g., tissue edema) all influence oximetry readings without necessarily affecting tissue oxygenation [25–27]. Other external sources of error or signal attenuation include motion artifact [28], non-hemoglobin chromophores, like melanin pigmentation in hair [29], and bilirubin in patients with jaundice [30]. Skin color and melanin content do not appear to negatively affect cerebral and tissue oximetry, as they are confined to the superficial part of the skin.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Clinical Applications

Mortality after major cardiac surgery remains low despite the rising number of aged and high-risk patients. Nevertheless, the frequency of neurologic complications remains relatively unchanged over the past decade [31]. Clinicians have long sought a reliable way to monitor the adequacy of brain perfusion during CPB, particularly considering the importance of neurologic complications, such as stroke, delirium, and cognitive impairment, for patient outcome. Proposed monitors for this purpose include quantitative electroencephalography (EEG), transcranial Doppler, and carotid Doppler, none of which have been adopted widely, mostly owing to associated technical limitations [32]. Despite its limitations, there has been wide enthusiasm for $rScO_2$ monitoring during cardiac surgery. It could offer a potentially large clinical benefit by alerting clinicians to a decrease in cerebral oxygen supply early enough to implement corrective interventions. Although some studies have shown that low $rScO_2$ values (either absolute or relative) are associated with poorer patient outcome (early postoperative cognitive decline) or longer length of hospitalization [33], available data are insufficient to convincingly establish that preventing or promptly correcting low $rScO_2$ values improves outcome [34, 35]. Given the relatively high cost of the monitoring sensors (~ $200 per patient) and the contradictory data on clear patient benefit, most authors agree that the routine use of cerebral or tissue oximetry as standard of care for *all* patients cannot be recommended at this time [8, 10, 36]. However, one often hears the counterargument that similar objections could be made for other standard-of-care monitors. For example, a resent Cochrane database review “found no evidence that pulse oximetry affects the outcome of anesthesia for patients” [37].

Cardiac Surgery

Many case reports and case series suggest that monitoring $rScO_2$ may provide early warning of CPB cannula malposition or rare, but catastrophic, oxygen delivery failure from the bypass circuit [38–40]. Several prospective observational studies found a link between decrements in $rScO_2$ from baseline and subtle neurologic changes, including postoperative delirium and cognitive dysfunction [22, 41–53]. These data, though, are not consistent, and the studies have had limitations, including small patient sample size, the use of a limited psychometric battery, and testing only early after surgery when many confounding factors can affect cognition. Several observational studies have found links between decrements in $rScO_2$ from baseline and postoperative stroke [22, 41, 54–56]. Goldman et al. [22] compared the rates of stroke in more than 1,000 patients who had $rScO_2$ monitoring during coronary artery bypass graft / valve surgery with stroke rates in a historical group. They found that the stroke rate was significantly higher in the group without cerebral monitoring (2.5% vs. 0.97%). However, the study used no defined protocol for managing patients with $rScO_2$ desaturation and made no statistical adjustment for potential confounding factors, such as with multivariate logistic regression analysis. This limitation is important, as the stroke rate in the monitored patients was lower than that in most series, raising the question of whether the historical group and the $rScO_2$-monitored group were at similar risk for stroke.

A larger question than any link between $rScO_2$ desaturation and patient outcome is whether corrective interventions can effectively reverse the desaturation and whether these

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

interventions lead to improved patient outcome. Murkin et al. [57] randomized 200 patients undergoing cardiac surgery to an intervention group with a specific protocol for managing $rScO_2$ desaturation (<75% of baseline value) and a control group who had $rScO_2$ blindly monitored. The algorithm for treating $rScO_2$ decrements included measures such as raising blood pressure, ensuring adequate CPB flow, normalizing $PaCO_2$, deepening anesthesia depth, or even instituting pulsatile CPB flow. These investigators found that control patients had longer desaturation times than patients in the intervention group ($p = 0.014$) and a longer duration of hospitalization in the intensive care unit ($p = 0.029$). Although major complications did not differ between the groups, the control patients were more likely to suffer major morbidity and mortality (death, ventilation >48 h, stroke, myocardial infarction, return for re-exploration) than were patients in the intervention group ($p = 0.048$). This study was not powered to compare the rates of stroke between the intervention and the control groups.

Based on these studies, even in this high-risk population, only low-level evidence links $rScO_2$ decrements from baseline to poor neurologic outcomes. Moreover, the available data are insufficient to conclude that interventions for correcting $rScO_2$ decrements lead to a lower risk for stroke, delirium, or postoperative cognitive dysfunction [9].

Pediatric Cardiac Surgery

Many groups have advocated for monitoring $rScO_2$ in pediatric patients undergoing cardiac surgery for congenital heart defects [68–71]. A retrospective analysis of 50 patients with hypoplastic left heart syndrome undergoing the Norwood procedure revealed that a mean $rScO_2 < 56\%$ for the first 48 postoperative hours has a sensitivity of 75% and a specificity of 79% for predicting adverse outcomes, such as death, prolonged intensive care unit stay, and need for extracorporeal membrane oxygenation [68]. Another small study in 25 pediatric surgery patients showed a positive correlation between $rScO_2$ and mixed venous oxygen saturation [70], whereas Bhutta and colleagues reported a correlation between cerebral oximetry and superior vena cava oxygen saturation in pediatric patients after heart transplant [71]. Moreover, intraoperative $rScO_2$ has been shown to be a sensitive indicator for the adequacy of cerebral perfusion in pediatric surgical patients who weigh less than 10 kg, as mixed venous oxygen saturation in those patients is more representative of lower body oxygenation [72]. Finally, one of the largest studies in pediatric cardiac surgery patients (n=250) evaluated different modalities of cerebral monitoring. Postoperative neurologic events occurred in 26% of patients who had a monitoring event that was not corrected intraoperatively but in only 6% of patients who received intraoperative treatment [73]. A recent systematic review of the role of $rScO_2$ in pediatric patients undergoing surgery for congenital heart disease identified 54 manuscripts (47 case series, 4 randomized trials, and 3 retrospective studies) and 13 review articles [74]. Taken together, the evidence failed to show that $rScO_2$ monitoring leads to a clinical improvement in short-term neurologic outcome in this patient population [74].

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

Carotid Artery Surgery

Carotid endarterectomy (CEA) surgery reduces the risk of stroke for patients with symptomatic carotid stenosis and subgroups of patients with asymptomatic stenosis [58–60]. These benefits are only realized if the rate of perioperative neurologic complications, including stroke, can be minimized. The risk for stroke after CEA depends on many factors, including the acuity and severity of symptoms and the individual center experience [61–63]. Ensuring cerebral perfusion to vascular territories ipsilateral to the side of carotid artery cross-clamping during CEA is paramount to reduce the risk of perioperative ischemic neurologic complications.

Clinicians use various strategies to monitor the adequacy of cerebral perfusion during carotid clamping, including stump pressure measurement (e.g., the blood pressure in the carotid artery distal to the cross clamp), transcranial Doppler, somatosensory evoked potentials (SSEPs), EEG, or use of regional anesthesia to allow assessment of the patient's mental status during carotid cross-clamping [64, 65]. Several investigations have examined the utility of monitoring $rScO_2$ during CEA surgery. One advantage of cerebral oximetry is that it is simple to use, particularly compared with multi-channel EEG and transcranial Doppler monitoring [64]. It has been reported that a 5% to 15% decrement in $rScO_2$ from baseline on the side ipsilateral to carotid cross-clamping has a 44% to 100% sensitivity and 44% to 100% specificity for predicting changes in CBF velocity as measured by transcranial Doppler, EEG slowing, or changes in SSEPs. [51–55] These studies have limitations such as small sample size. One of the largest studies to date, which involved almost 600 patients who underwent CEA under general anesthesia, found that a 11.7% decrease from baseline in $rScO_2$ had a sensitivity of 75% and a specificity of 77% for detecting neurological complications [66]. Others have reported that decrements in $rScO_2 \geq 20\%$ from baseline were associated with neurologic symptoms during carotid artery cross-clamping in patients undergoing CEA with regional anesthesia. [57] The sensitivity of changes in $rScO_2$ compared with neurologic symptoms in awake patients was 80%, with a specificity of 82%.

Clinicians must consider that lower specificity, or false positive results, for detecting cerebral ischemia with $rScO_2$ monitoring may lead to unnecessary treatment—including shunt placement, which by itself carries a risk of embolic stroke [67]. False negative results may also have considerable consequences. In one study, $rScO_2$ was unchanged in 7 of 323 patients during carotid artery cross-clamping for CEA, despite evidence of cerebral ischemia based on EEG or SSEP monitoring. [56] In that study, the authors observed a discrepancy between $rScO_2$ findings and EEG and SSEP results in 24 (7.4%) patients. Thus, the current evidence suggests that $rScO_2$ may not have high clinical reliability as a sole monitor of the adequacy of cerebral perfusion during CEA surgery.

Emerging Applications

Cerebral Autoregulation

The main determinants of $rScO_2$ include oxygen content of the blood, CBF, tissue diffusivity of oxygen, and cerebral metabolic rate for oxygen. Because factors that affect blood oxygen content and cerebral metabolic rate are relatively stable over short periods of

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

time, members of our group have proposed that $rScO_2$ might serve as a clinically useful surrogate for CBF during bedside monitoring of cerebral autoregulation. Using $rScO_2$ signals from a standard NIRS monitor, specialized computer software calculates the continuous correlation between low-frequency (20 sec to 3 min) changes in $rScO_2$ and mean arterial blood pressure to render the variable cerebral oximetry index (COx) [6, 75, 76]. This approach is based on the rationale that CBF in the autoregulated range is constant regardless of blood pressure. Thus, when autoregulation is functional, the metrics of CBF and blood pressure do not correlate, and COx approaches zero or is negative. Conversely, when blood pressure is below or above the limits of autoregulation, the metrics of CBF and blood pressure do correlate, and COx approaches 1. An example of COx monitoring in a patient undergoing cardiac surgery with cardiopulmonary bypass is shown in Figure 2. Our approach was validated in a laboratory piglet model by comparing COx monitoring to laser Doppler flux measurement of CBF [77]. We have further validated COx monitoring by comparing it to transcranial Doppler monitoring in adult patients undergoing CPB [78]. Monitoring of COx has many advantages over other methods of autoregulation monitoring, as it is noninvasive, provides a continuous measurement that is not subject to electrical or motion artifact as transcranial Doppler monitoring is, and requires little caregiver intervention. We have validated a “plug-and-play” custom NIRS monitor that holds promise for providing clinicians with a feasible method of COx monitoring [79].

In our research thus far, we have made several clinically important observations, primarily in patients undergoing cardiac surgery. First, we have found that the mean arterial pressure at the lower limit of autoregulation varies widely between individuals, ranging from 40 to 90 mmHg [6, 80–82]. Consequently, when standard empiric methods are used to set blood pressure limits during cardiopulmonary bypass (or to define the tolerance to low blood pressure), some patients will have periods during surgery when their blood pressure is below the limits of autoregulation. These excursions of blood pressure below the lower limit of autoregulation were found to be associated with the risk for acute kidney injury after cardiac surgery and major organ morbidity and mortality [83, 84]. Monitoring COx might provide a means to individualize blood pressure targets during surgery and modify risk for adverse patient outcomes.

Tissue Perfusion

Although most clinical and research applications of NIRS monitoring focus on $rScO_2$ monitoring, the principle of light penetration into tissues and the absorption by chromophores is applicable to multiple regions of the body [85]. The muscle underlying the thenar eminence has been identified as a relatively homogeneous tissue compartment. Because it has a reasonably small overlying fat layer, only minor inter-individual variations, little tendency to develop edema, and little pigmentation, it can be easily accessed for NIRS [85]. Studies have shown that the distal extremities exhibit an early vasoconstrictor response in models of hypovolemia [86, 87]. Therefore, monitoring of thenar tissue oxygenation may be beneficial for detecting early signs of hypovolemia in patients who are still hemodynamically compensated and provide a guide to therapy before changes occur in traditional markers of volume status [88]. A minimum tissue oxygen value, as measured by NIRS, precedes peak lactate levels by more than 90 min in patients with hypovolemic shock,

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

indicating that regional tissue perfusion might be an earlier indicator of perfusion deficits [89]. Other potential sites that NIRS monitoring might be applied to (especially in the pediatric population) include relatively superficial organs like the kidney or gut [90–92]. In a study of 23 pediatric cardiac surgery patients, cerebral, splanchnic, renal, and muscle oximetry correlated with lactate levels [92]. Emerging data also support the possibility of using tissue oximetry to measure renovascular reactivity during hemorrhagic shock [93, 94]. Lastly, tissue oximetry could be used as an early marker to detect intraoperative tissue hypoxia during abdominal surgery that involves the intestines, pancreas, or kidneys [95, 96]. The major drawback to evaluating oxygenation of superficial organs with NIRS methodology is the large inter-individual variability in distance between the body surface and the organ of interest, secondary to overlying fat and muscle. The latter contains myoglobin, a chromophore that makes it difficult to distinguish light absorption arising from hemoglobin. Nevertheless some clinical data (mainly limited to small studies and case reports) suggest that tissue oximetry has value, especially in the pediatric population [97].

Acknowledgments

Funding Source:

Supported in part by a grant to Dr. Hogue from the National Institutes of Health (R01 HL092259-1).

Charles W Hogue, Jr: Research funding from Covidien, Inc (Boulder, CO), Advisory Board membership for Ornim (Israel), Data and Safety Montioring Board, CSL Behring (King of Prussia, PA).

References

1. Jobsis FF. Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science. 1977; 198:1264–1267. [PubMed: 929199]
2. Ferrari MQV. Review Near infrared brain muscle oximetry: from the discovery to current applications. Journal of Near Infrared Spectroscopy. 2012; 20:1–14.
3. Ferrari M, Giannini I, Sideri G, Zanette E. Continuous non invasive monitoring of human brain by near infrared spectroscopy. Advances in experimental medicine and biology. 1985; 191:873–882. [PubMed: 3008520]
4. Murkin JM, Arango M. Near-infrared spectroscopy as an index of brain and tissue oxygenation. British journal of anaesthesia. 2009; 103(Suppl 1):i3–i13. [PubMed: 20007987]
5. Cerbo RM, Cabano R, Di Comite A, Longo S, Maragliano R, Stronati M. Cerebral and somatic rSO2 in sick preterm infants. The journal of maternal-fetal & neonatal medicine : the official journal of the European Association of Perinatal Medicine, the Federation of Asia and Oceania Perinatal Societies, the International Society of Perinatal Obstet. 2012; 25(Suppl 4):97–100.
6. Brady K, Joshi B, Zweifel C, Smielewski P, Czosnyka M, Easley RB, et al. Real-time continuous monitoring of cerebral blood flow autoregulation using near-infrared spectroscopy in patients undergoing cardiopulmonary bypass. Stroke; a journal of cerebral circulation. 2010; 41:1951–1956.
7. Owens GE, King K, Gurney JG, Charpie JR. Low renal oximetry correlates with acute kidney injury after infant cardiac surgery. Pediatric cardiology. 2011; 32:183–188. [PubMed: 21085945]
8. Ghosh A, Elwell C, Smith M. Review article: cerebral near-infrared spectroscopy in adults: a work in progress. Anesthesia and analgesia. 2012; 115:1373–1383. [PubMed: 23144435]
9. Zheng F, Sheinberg R, Yee MS, Ono M, Zheng Y, Hogue CW. Cerebral near-infrared spectroscopy monitoring and neurologic outcomes in adult cardiac surgery patients: a systematic review. Anesthesia and analgesia. 2013; 116:663–676. [PubMed: 23267000]
10. Wolf M, Ferrari M, Quaresima V. Progress of near-infrared spectroscopy and topography for brain and muscle clinical applications. Journal of biomedical optics. 2007; 12:062104. [PubMed: 18163807]

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

11. Rolfe P. In vivo near-infrared spectroscopy. Annual review of biomedical engineering. 2000; 2:715–754.
12. Huppert TJ, Diamond SG, Franceschini MA, Boas DA. HomER: a review of time-series analysis methods for near-infrared spectroscopy of the brain. Applied optics. 2009; 48:D280–D298. [PubMed: 19340120]
13. Robles FE, Chowdhury S, Wax A. Assessing hemoglobin concentration using spectroscopic optical coherence tomography for feasibility of tissue diagnostics. Biomedical optics express. 2010; 1:310–317. [PubMed: 21258468]
14. Cheong WF, Prahl SA, Welch AJ. A Review of the Optical-Properties of Biological Tissues. Ieee J Quantum Elect. 1990; 26:2166–2185.
15. Suzuki S, Takasaki S, Ozaki T, Kobayashi Y. A tissue oxygenation monitor using NIR spatially resolved spectroscopy. P Soc Photo-Opt Ins. 1999; 3597:582–592.
16. Wabnitz H, Moeller M, Liebert A, Obrig H, Steinbrink J, Macdonald R. Time-resolved near-infrared spectroscopy and imaging of the adult human brain. Advances in experimental medicine and biology. 2010; 662:143–148. [PubMed: 20204784]
17. Lakowicz JR, Berndt K. Frequency-Domain Measurements of Photon Migration in Tissues. Chem Phys Lett. 1990; 166:246–252.
18. Kurth CD, Thayer WS. A multiwavelength frequency-domain near-infrared cerebral oximeter. Physics in medicine and biology. 1999; 44:727–740. [PubMed: 10211806]
19. Matcher SJ, Elwell CE, Cooper CE, Cope M, Delpy DT. Performance comparison of several published tissue near-infrared spectroscopy algorithms. Analytical biochemistry. 1995; 227:54–68. [PubMed: 7668392]
20. Thavasothy M, Broadhead M, Elwell C, Peters M, Smith M. A comparison of cerebral oxygenation as measured by the NIRO 300 and the INVOS 5100 Near-Infrared Spectrophotometers. Anaesthesia. 2002; 57:999–1006. [PubMed: 12358958]
21. Germon TJ, Evans PD, Barnett NJ, Wall P, Manara AR, Nelson RJ. Cerebral near infrared spectroscopy: emitter-detector separation must be increased. Br J Anaesth. 1999; 82:831–837. [PubMed: 10562774]
22. Goldman S, Sutter F, Ferdinand F, Trace C. Optimizing intraoperative cerebral oxygen delivery using noninvasive cerebral oximetry decreases the incidence of stroke for cardiac surgical patients. The heart surgery forum. 2004; 7:E376–E381. [PubMed: 15799908]
23. Watzman HM, Kurth CD, Montenegro LM, Rome J, Steven JM, Nicolson SC. Arterial and venous contributions to near-infrared cerebral oximetry. Anesthesiology. 2000; 93:947–953. [PubMed: 11020744]
24. Ito H, Ibaraki M, Kanno I, Fukuda H, Miura S. Changes in the arterial fraction of human cerebral blood volume during hypercapnia and hypocapnia measured by positron emission tomography. J Cereb Blood Flow Metab. 2005; 25:852–857. [PubMed: 15716851]
25. Yoshitani K, Kawaguchi M, Iwata M, Sasaoka N, Inoue S, Kurumatani N, et al. Comparison of changes in jugular venous bulb oxygen saturation and cerebral oxygen saturation during variations of haemoglobin concentration under propofol and sevoflurane anaesthesia. British journal of anaesthesia. 2005; 94:341–346. [PubMed: 15591331]
26. Pattinson KT, Imray CH, Wright AD. What does cerebral oximetry measure? British journal of anaesthesia. 2005; 94:863. author reply -4. [PubMed: 15878895]
27. Yoshitani K, Kawaguchi M, Miura N, Okuno T, Kanoda T, Ohnishi Y, et al. Effects of hemoglobin concentration, skull thickness, and the area of the cerebrospinal fluid layer on near-infrared spectroscopy measurements. Anesthesiology. 2007; 106:458–462. [PubMed: 17325503]
28. Cooper RJ, Selb J, Gagnon L, Phillip D, Schytz HW, Iversen HK, et al. A systematic comparison of motion artifact correction techniques for functional near-infrared spectroscopy. Frontiers in neuroscience. 2012; 6:147. [PubMed: 23087603]
29. Pringle J, Roberts C, Kohl M, Lekeux P. Near infrared spectroscopy in large animals: Optical pathlength and influence of hair covering and epidermal pigmentation. Vet J. 1999; 158:48–52. [PubMed: 10409416]
30. Madsen PL, Skak C, Rasmussen A, Secher NH. Interference of cerebral near-infrared oximetry in patients with icterus. Anesthesia and analgesia. 2000; 90:489–493. [PubMed: 10648345]

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

31. Fischer GW. Recent advances in application of cerebral oximetry in adult cardiovascular surgery. Seminars in cardiothoracic and vascular anesthesia. 2008; 12:60–69. [PubMed: 18397905]
32. Edmonds HL Jr. 2010 standard of care for central nervous system monitoring during cardiac surgery. J Cardiothorac Vasc Anesth. 2010; 24:541–543. [PubMed: 20561799]
33. Casati A, Fanelli G, Pietropaoli P, Proietti R, Tufano R, Montanini S, et al. Monitoring cerebral oxygen saturation in elderly patients undergoing general abdominal surgery: a prospective cohort study. European journal of anaesthesiology. 2007; 24:59–65. [PubMed: 16824246]
34. Casati A, Fanelli G, Pietropaoli P, Proietti R, Tufano R, Danelli G, et al. Continuous monitoring of cerebral oxygen saturation in elderly patients undergoing major abdominal surgery minimizes brain exposure to potential hypoxia. Anesthesia and analgesia. 2005; 101:740–747. table of contents. [PubMed: 16115985]
35. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS, et al. Cerebral oxygen desaturation events assessed by near-infrared spectroscopy during shoulder arthroscopy in the beach chair and lateral decubitus positions. Anesthesia and analgesia. 2010; 111:496–505. [PubMed: 20508134]
36. Highton D, Elwell C, Smith M. Noninvasive cerebral oximetry: is there light at the end of the tunnel? Current opinion in anaesthesiology. 2010; 23:576–581. [PubMed: 20830845]
37. Pedersen T, Moller AM, Hovhannisyan K. Pulse oximetry for perioperative monitoring. Cochrane Database Syst Rev. 2009:CD002013. [PubMed: 19821289]
38. Vernick WJ, Oware A. Early diagnosis of superior vena cava obstruction facilitated by the use of cerebral oximetry. Journal of cardiothoracic and vascular anesthesia. 2011; 25:1101–1103. [PubMed: 21115365]
39. Prabhune A, Sehic A, Spence PA, Church T, Edmonds HL Jr. Cerebral oximetry provides early warning of oxygen delivery failure during cardiopulmonary bypass. Journal of cardiothoracic and vascular anesthesia. 2002; 16:204–206. [PubMed: 11957172]
40. Blas ML, Lobato EB, Martin T. Noninvasive infrared spectroscopy as a monitor of retrograde cerebral perfusion during deep hypothermia. Journal of cardiothoracic and vascular anesthesia. 1999; 13:244–245. [PubMed: 10230970]
41. Fischer GW, Lin HM, Krol M, Galati MF, Di Luozzo G, Griepp RB, et al. Noninvasive cerebral oxygenation may predict outcome in patients undergoing aortic arch surgery. The Journal of thoracic and cardiovascular surgery. 2011; 141:815–821. [PubMed: 20579669]
42. Schoen J, Meyerrose J, Paarmann H, Heringlake M, Hueppe M, Berger KU. Preoperative regional cerebral oxygen saturation is a predictor of postoperative delirium in on-pump cardiac surgery patients: a prospective observational trial. Critical care. 2011; 15:R218. [PubMed: 21929765]
43. Liu N, Sun LZ, Chang Q, Yang JG. [Clinical application of cerebral oxygenation monitoring during aortic aneurysm operation]. Zhonghua yi xue za zhi. 2007; 87:1030–1033. [PubMed: 17672965]
44. Negargar S, Mahmoudpour A, Taheri R, Sanaie S. The relationship between cerebral oxygen saturation changes & post operative. Pak J Med Sci. 2007; 23:380–385.
45. Hong SW, Shim JK, Choi YS, Kim DH, Chang BC, Kwak YL. Prediction of cognitive dysfunction and patients' outcome following valvular heart surgery and the role of cerebral oximetry. European journal of cardio-thoracic surgery : official journal of the European Association for Cardio-thoracic Surgery. 2008; 33:560–565. [PubMed: 18272385]
46. Reents W, Muellges W, Franke D, Babin-Ebell J, Elert O. Cerebral oxygen saturation assessed by near-infrared spectroscopy during coronary artery bypass grafting and early postoperative cognitive function. The Annals of thoracic surgery. 2002; 74:109–114. [PubMed: 12118739]
47. Orihashi K, Sueda T, Okada K, Imai K. Malposition of selective cerebral perfusion catheter is not a rare event. European journal of cardio-thoracic surgery : official journal of the European Association for Cardio-thoracic Surgery. 2005; 27:644–648. [PubMed: 15784366]
48. Rubio A, Hakami L, Munch F, Tandler R, Harig F, Weyand M. Noninvasive control of adequate cerebral oxygenation during low-flow antegrade selective cerebral perfusion on adults and infants in the aortic arch surgery. Journal of cardiac surgery. 2008; 23:474–479. [PubMed: 18928485]
49. Schoen J, Husemann L, Tiemeyer C, Lueloh A, Sedemund-Adib B, Berger KU, et al. Cognitive function after sevoflurane- vs propofol-based anaesthesia for on-pump cardiac surgery: a

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

randomized controlled trial. British journal of anaesthesia. 2011; 106:840–850. [PubMed: 21518736]

50. de Tournay-Jette E, Dupuis G, Bherer L, Deschamps A, Cartier R, Denault A. The relationship between cerebral oxygen saturation changes and postoperative cognitive dysfunction in elderly patients after coronary artery bypass graft surgery. Journal of cardiothoracic and vascular anesthesia. 2011; 25:95–104. [PubMed: 20650659]
51. Fudickar A, Peters S, Stapelfeldt C, Serocki G, Leiendecker J, Meybohm P, et al. Postoperative cognitive deficit after cardiopulmonary bypass with preserved cerebral oxygenation: a prospective observational pilot study. BMC anesthesiology. 2011; 11:7. [PubMed: 21401948]
52. Nollert G, Mohnle P, Tassani-Prell P, Uttner I, Borasio GD, Schmoeckel M, et al. Postoperative neuropsychological dysfunction and cerebral oxygenation during cardiac surgery. The Thoracic and cardiovascular surgeon. 1995; 43:260–264. [PubMed: 8610284]
53. Yao FS, Tseng CC, Ho CY, Levin SK, Illner P. Cerebral oxygen desaturation is associated with early postoperative neuropsychological dysfunction in patients undergoing cardiac surgery. Journal of cardiothoracic and vascular anesthesia. 2004; 18:552–558. [PubMed: 15578464]
54. Orihashi K, Sueda T, Okada K, Imai K. Near-infrared spectroscopy for monitoring cerebral ischemia during selective cerebral perfusion. European journal of cardio-thoracic surgery : official journal of the European Association for Cardio-thoracic Surgery. 2004; 26:907–911. [PubMed: 15519181]
55. Olsson C, Thelin S. Regional cerebral saturation monitoring with near-infrared spectroscopy during selective antegrade cerebral perfusion: diagnostic performance and relationship to postoperative stroke. The Journal of thoracic and cardiovascular surgery. 2006; 131:371–379. [PubMed: 16434267]
56. Edmonds HL Jr. Protective effect of neuromonitoring during cardiac surgery. Annals of the New York Academy of Sciences. 2005; 1053:12–19. [PubMed: 16179501]
57. Murkin JM, Adams SJ, Novick RJ, Quantz M, Bainbridge D, Iglesias I, et al. Monitoring brain oxygen saturation during coronary bypass surgery: a randomized, prospective study. Anesthesia and analgesia. 2007; 104:51–58. [PubMed: 17179242]
58. Rothwell PM, Eliasziw M, Gutnikov SA, Fox AJ, Taylor DW, Mayberg MR, et al. Analysis of pooled data from the randomised controlled trials of endarterectomy for symptomatic carotid stenosis. Lancet. 2003; 361:107–116. [PubMed: 12531577]
59. Group ECSTC. Randomised trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial (ECST). Lancet. 1998; 351:1379–1387. [PubMed: 9593407]
60. Collaborators NASCET. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Engl J Med. 1991; 325:445–453. [PubMed: 1852179]
61. Brott TG, Halperin JL, Abbara S, Bacharach JM, Barr JD, Bush RL, et al. 2011 ASA/ACCF/AHA/AANN/AANS/ACR/ASNR/CNS/SAIP/SCAI/SIR/SNIS/SVM/SVS guideline on the management of patients with extracranial carotid and vertebral artery disease: executive summary. Stroke; a journal of cerebral circulation. 2011; 42:e420–e463.
62. Thapar A, Jenkins IH, Mehta A, Davies AH. Diagnosis and management of carotid atherosclerosis. Bmj. 2013; 346:f1485. [PubMed: 23507536]
63. Wu TY, Anderson NE, Barber PA. Neurological complications of carotid revascularisation. Journal of neurology, neurosurgery, and psychiatry. 2012; 83:543–550.
64. Pennekamp CW, Bots ML, Kappelle LJ, Moll FL, de Borst GJ. The value of near-infrared spectroscopy measured cerebral oximetry during carotid endarterectomy in perioperative stroke prevention. A review. Eur J Vasc Endovasc Surg. 2009; 38:539–545. [PubMed: 19665397]
65. Moritz S, Kasprzak P, Arlt M, Taeger K, Metz C. Accuracy of cerebral monitoring in detecting cerebral ischemia during carotid endarterectomy: a comparison of transcranial Doppler sonography, near-infrared spectroscopy, stump pressure, and somatosensory evoked potentials. Anesthesiology. 2007; 107:563–569. [PubMed: 17893451]
66. Mille T, Tachimiri ME, Klersy C, Ticozzelli G, Bellinzona G, Blangetti I, et al. Near infrared spectroscopy monitoring during carotid endarterectomy: which threshold value is critical? Eur J Vasc Endovasc Surg. 2004; 27:646–650. [PubMed: 15121117]

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

67. Grubhofer G, Plochl W, Skolka M, Czerny M, Ehrlich M, Lassnigg A. Comparing Doppler ultrasonography and cerebral oximetry as indicators for shunting in carotid endarterectomy. Anesthesia and analgesia. 2000; 91:1339–1344. [PubMed: 11093976]
68. Phelps HM, Mahle WT, Kim D, Simsic JM, Kirshbom PM, Kanter KR, et al. Postoperative cerebral oxygenation in hypoplastic left heart syndrome after the Norwood procedure. The Annals of thoracic surgery. 2009; 87:1490–1494. [PubMed: 19379890]
69. Yamamoto A, Yokoyama N, Yonetani M, Uetani Y, Nakamura H, Nakao H. Evaluation of change of cerebral circulation by SpO2 in preterm infants with apneic episodes using near infrared spectroscopy. Pediatr Int. 2003; 45:661–664. [PubMed: 14651537]
70. Tortoriello TA, Stayer SA, Mott AR, McKenzie ED, Fraser CD, Andropoulos DB, et al. A noninvasive estimation of mixed venous oxygen saturation using near-infrared spectroscopy by cerebral oximetry in pediatric cardiac surgery patients. Paediatr Anaesth. 2005; 15:495–503. [PubMed: 15910351]
71. Bhutta AT, Ford JW, Parker JG, Prodhan P, Fontenot EE, Seib PM, et al. Noninvasive cerebral oximeter as a surrogate for mixed venous saturation in children. Pediatr Cardiol. 2007; 28:34–41. [PubMed: 17219027]
72. Redlin M, Koster A, Huebler M, Boettcher W, Nagdyman N, Hetzer R, et al. Regional differences in tissue oxygenation during cardiopulmonary bypass for correction of congenital heart disease in neonates and small infants: relevance of near-infrared spectroscopy. The Journal of thoracic and cardiovascular surgery. 2008; 136:962–967. [PubMed: 18954637]
73. Austin EH 3rd, Edmonds HL Jr, Auden SM, Seremet V, Niznik G, Sehic A, et al. Benefit of neurophysiologic monitoring for pediatric cardiac surgery. The Journal of thoracic and cardiovascular surgery. 1997; 114:707–715. 17; discussion 15–6. [PubMed: 9375600]
74. Hirsch JC, Charpie JR, Ohye RG, Gurney JG. Near-infrared spectroscopy: what we know and what we need to know--a systematic review of the congenital heart disease literature. The Journal of thoracic and cardiovascular surgery. 2009; 137:154–159. 9e1–9e12. [PubMed: 19154918]
75. Brady KM, Lee JK, Kibler KK, Smielewski P, Czosnyka M, Easley RB, et al. Continuous time-domain analysis of cerebrovascular autoregulation using near-infrared spectroscopy. Stroke; a journal of cerebral circulation. 2007; 38:2818–2825.
76. Czosnyka M, Brady K, Reinhard M, Smielewski P, Steiner LA. Monitoring of cerebrovascular autoregulation: facts, myths, and missing links. Neurocrit Care. 2009; 10:373–386. [PubMed: 19127448]
77. Brady KM, Lee JK, Kibler KK, Smielewski P, Czosnyka M, Easley RB, et al. Continuous time-domain analysis of cerebrovascular autoregulation using near-infrared spectroscopy. Stroke. 2007; 38:2818–2825. [PubMed: 17761921]
78. Brady K, Joshi B, Zweifel C, Smielewski P, Czosnyka M, Easley RB, et al. Real-time continuous monitoring of cerebral blood flow autoregulation using near-infrared spectroscopy in patients undergoing cardiopulmonary bypass. Stroke. 2010; 41:1951–1956. [PubMed: 20651274]
79. Joshi B, Brady K, Lee J, Easley B, Panigrahi R, Smielewski P, et al. Impaired autoregulation of cerebral blood flow during rewarming from hypothermic cardiopulmonary bypass and its potential association with stroke. Anesthesia and analgesia. 2010; 110:321–328. [PubMed: 20008083]
80. Joshi B, Brady K, Lee J, Easley B, Panigrahi R, Smielewski P, et al. Impaired autoregulation of cerebral blood flow during rewarming from hypothermic cardiopulmonary bypass and its potential association with stroke. Anesth Analg. 2010; 110:321–328. [PubMed: 20008083]
81. Ono M, Joshi B, Brady K, Easley RB, Zheng Y, Brown C, et al. Risks for impaired cerebral autoregulation during cardiopulmonary bypass and postoperative stroke. Br J Anaesth. 2012; 109:391–398. [PubMed: 22661748]
82. Ono M, Arnaoutakis GJ, Fine DM, Brady K, Easley RB, Zheng Y, et al. Blood pressure excursions below the cerebral autoregulation threshold during cardiac surgery are associated with acute kidney injury. Critical care medicine. 2013; 41:464–471. [PubMed: 23263580]
83. Ono M, Joshi B, Brady K, Easley RB, Zheng Y, Brown C, et al. Risks for impaired cerebral autoregulation during cardiopulmonary bypass and postoperative stroke. Br J Anaesth. 2012; 109:391–398. [PubMed: 22661748]

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript

84. Ono M, Arnaoutakis GJ, Fine DM, Brady K, Easley RB, Zheng Y, et al. Blood pressure excursions below the cerebral autoregulation threshold during cardiac surgery are associated with acute kidney injury. Critical care medicine. 2013; 41:464–471. [PubMed: 23263580]
85. Scheeren TW, Schober P, Schwarte LA. Monitoring tissue oxygenation by near infrared spectroscopy (NIRS): background and current applications. J Clin Monit Comput. 2012; 26:279–287. [PubMed: 22467064]
86. Cole AL, Herman RA Jr, Heimlich JB, Ahsan S, Freedman BA, Shuler MS. Ability of near infrared spectroscopy to measure oxygenation in isolated upper extremity muscle compartments. J Hand Surg Am. 2012; 37:297–302. [PubMed: 22189186]
87. Bartels SA, Bezemer R, de Vries FJ, Milstein DM, Lima A, Cherpanath TG, et al. Multi-site and multi-depth near-infrared spectroscopy in a model of simulated (central) hypovolemia: lower body negative pressure. Intensive care medicine. 2011; 37:671–677. [PubMed: 21253704]
88. Beekley AC, Martin MJ, Nelson T, Grathwohl KW, Griffith M, Beilman G, et al. Continuous noninvasive tissue oximetry in the early evaluation of the combat casualty: a prospective study. The Journal of trauma. 2010; 69(Suppl 1):S14–S25. [PubMed: 20622608]
89. Putnam B, Bricker S, Fedorka P, Zelada J, Shebrain S, Omari B, et al. The correlation of near-infrared spectroscopy with changes in oxygen delivery in a controlled model of altered perfusion. The American surgeon. 2007; 73:1017–1022. [PubMed: 17983072]
90. Danduran MJ, Dixon JE, Rao RP. Near infrared spectroscopy describes physiologic payback associated with excess postexercise oxygen consumption in healthy controls and children with complex congenital heart disease. Pediatr Cardiol. 2012; 33:95–102. [PubMed: 21892649]
91. Petrova A, Mehta R. Near-infrared spectroscopy in the detection of regional tissue oxygenation during hypoxic events in preterm infants undergoing critical care. Pediatr Crit Care Med. 2006; 7:449–454. [PubMed: 16885790]
92. Kaufman J, Almodovar MC, Zuk J, Friesen RH. Correlation of abdominal site near-infrared spectroscopy with gastric tonometry in infants following surgery for congenital heart disease. Pediatr Crit Care Med. 2008; 9:62–68. [PubMed: 18477915]
93. Rhee CJ, Kibler KK, Easley RB, Andropoulos DB, Czosnyka M, Smielewski P, et al. Renovascular reactivity measured by near-infrared spectroscopy. J Appl Physiol (1985). 2012; 113:307–314. [PubMed: 22628378]
94. O'Connor PM, Anderson WP, Kett MM, Evans RG. Simultaneous measurement of pO2 and perfusion in the rabbit kidney in vivo. Advances in experimental medicine and biology. 2007; 599:93–99. [PubMed: 17727252]
95. Rasekhi A, Sharifian M, Kazemi K, Hosseini SA. The use of micro pulse oximetery as a new detector of tissue perfusion in solid organ transplantation. Saudi J Kidney Dis Transpl. 2012; 23:715–718. [PubMed: 22805382]
96. Servais EL, Rizk NP, Oliveira L, Rusch VW, Bikson M, Adusumilli PS. Real-time intraoperative detection of tissue hypoxia in gastrointestinal surgery by wireless pulse oximetry. Surg Endosc. 2011; 25:1383–1389. [PubMed: 20972585]
97. Mittnacht AJ. Near infrared spectroscopy in children at high risk of low perfusion. Curr Opin Anaesthesiol. 2010; 23:342–347. [PubMed: 20421789]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Practice Points

- Cerebral and tissue oximetry are simple and attractive ways to measure regional oxygenation
- Data are insufficient to recommend cerebral and tissue oximetry as standard-of-care monitoring for *all* patients undergoing anesthesia
- Patients undergoing cardiac surgery and carotid endarterectomy are more likely than other patients to benefit from cerebral oximetry
- Emerging data suggest that tissue oximetry provides complementary information for patients in hemorrhagic shock and for pediatric patients with impaired intestinal or renal perfusion
- By serving as a surrogate for CBF, cerebral oximetry may offer a clinically feasible method to monitor cerebral autoregulation

Research Agenda

- Define patient populations that will most likely benefit from cerebral and tissue oximetry
- Evaluate the risks and benefits of interventions to maintain blood pressure within an individual's autoregulation range during surgery and in the intensive care unit
- Validate tissue and organ NIRS monitoring

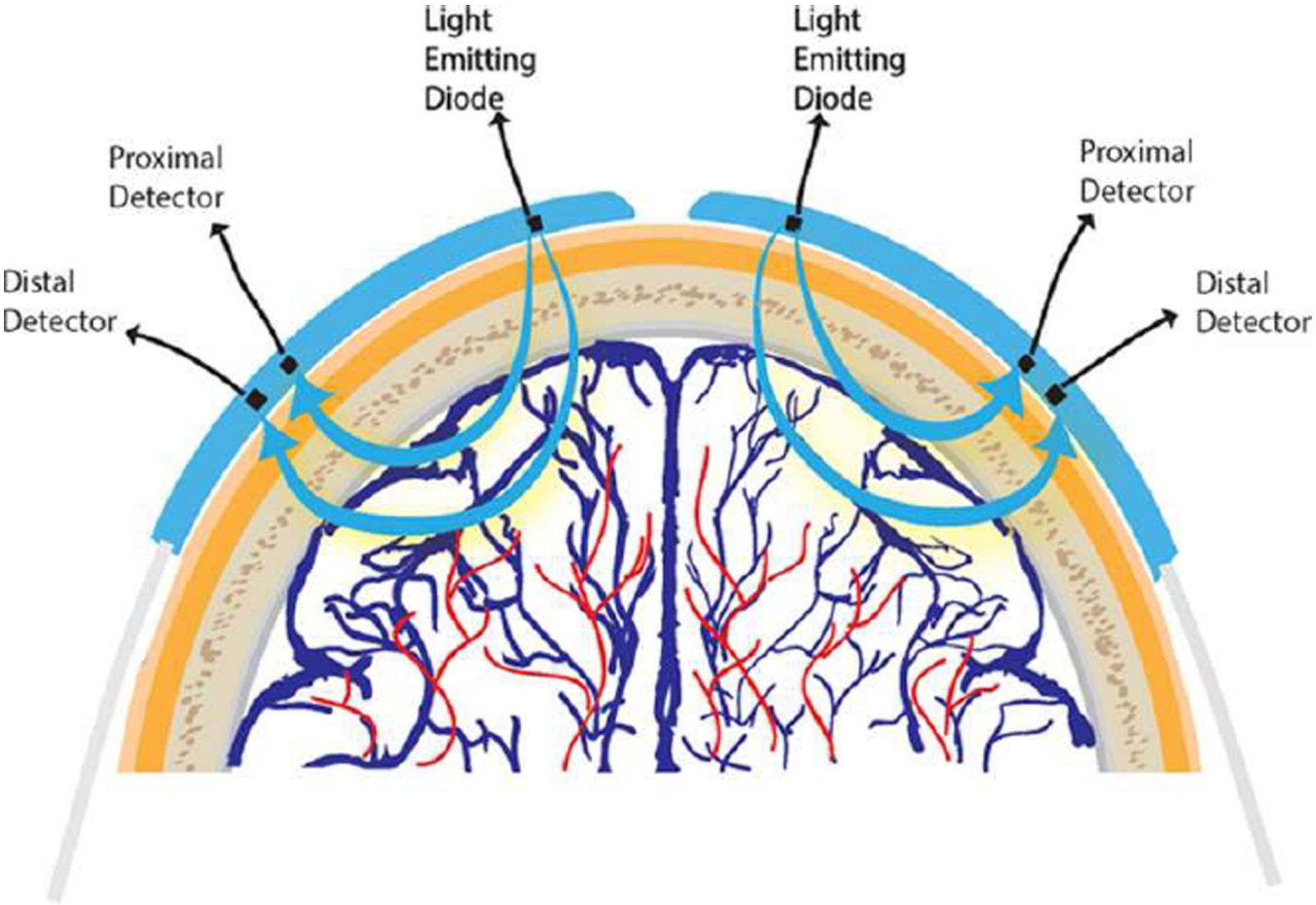
Summary

Cerebral or tissue oximetry is a simple and attractive way to measure regional oxygenation. This method takes advantage of the fact that light in the near-infrared spectrum penetrates tissue, including bone and muscle. When sensors are placed at fixed distances from a light emitter, computer algorithms can subtract superficial light absorption from deep absorption to provide an index of tissue oxygenation. Despite the growing popularity of this monitoring technique, data regarding outcome benefits remain sparse and contradictory. Even in high-risk patients undergoing cardiac surgery, only low-level evidence has shown a correlation between detection of low cerebral oxygen saturations with NIRS and poor neurologic outcomes. Available data are insufficient to conclude that interventions guided by cerebral oximetry improve neurologic outcome by reducing stroke rate and postoperative cognitive dysfunction. Therefore most authors agree that the routine use of cerebral or tissue oximetry as standard of care for *all* patients cannot be recommended at this time. Novel areas of application for NIRS include cerebral autoregulation and tissue oxygenation (e.g., kidneys and the gut). Additional studies are needed to evaluate the risks and benefits of using interventions to maintain blood pressure within an individual's autoregulation range and to maintain peripheral tissue and end organ oxygenation.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript



NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

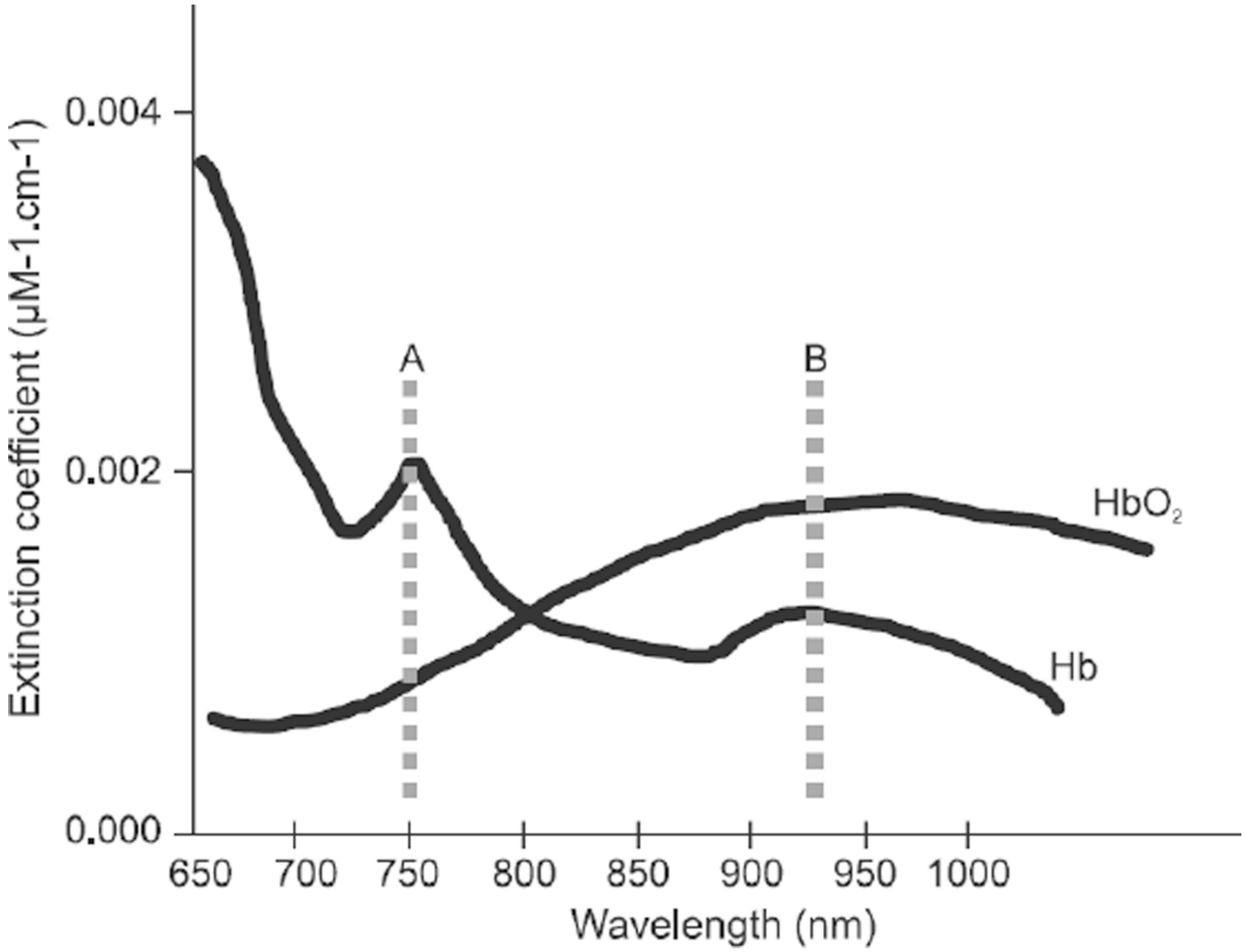


Fig. 1.

Cerebral oximetry. A: Schematic illustration of cerebral oximetry. Used with permission from Anesth Analg. 2013 Mar;116(3):663-76 B: Absorption spectrum of hemoglobin and oxyhemoglobin with the peak absorption wavelength of oxyhemoglobin (B: 920 nm) and total hemoglobin (A: 760 nm). Hb, deoxyhemoglobin; HbO_2, oxyhemoglobin. Used with permission from Lima et al., Rev Bras Ter Intensiva. 2011 August 23(3):341–351.

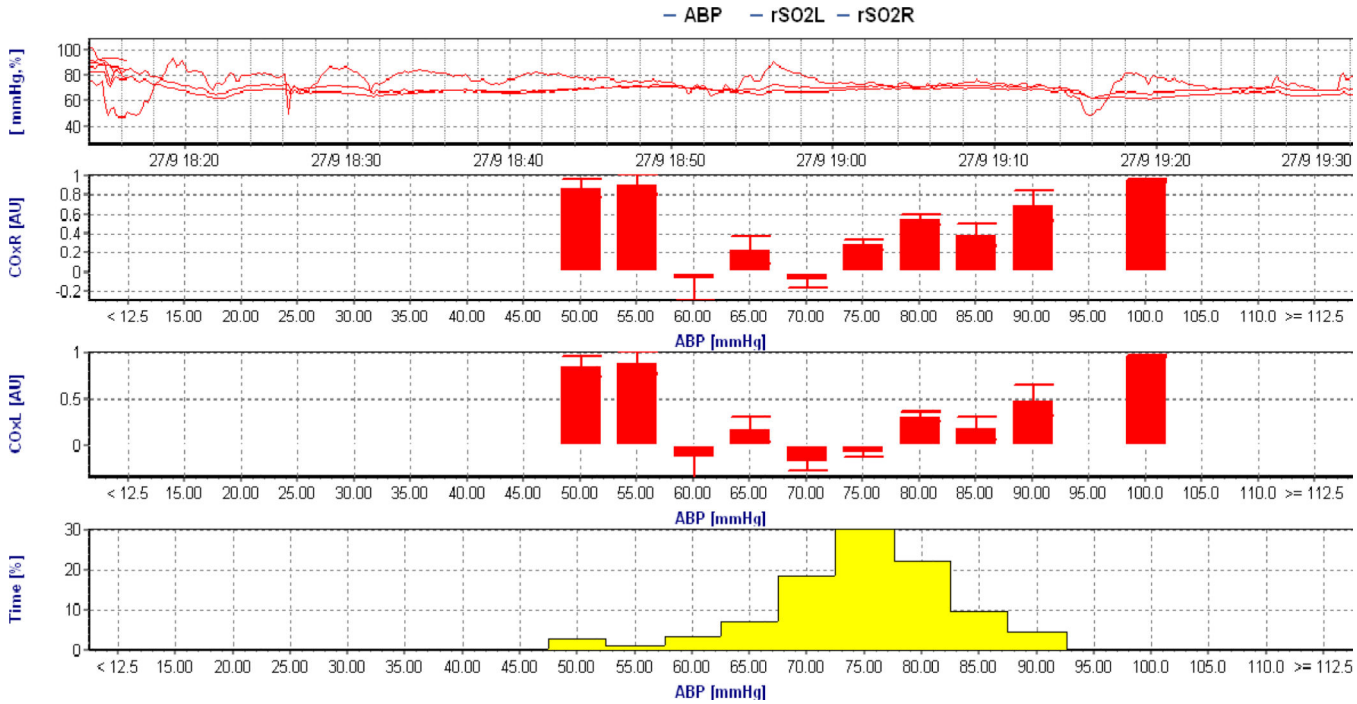


Fig. 2.

Cerebral oximetry index (COx) recording from a patient undergoing cardiopulmonary bypass. The top graph is the time series for mean arterial pressure (ABP) and the raw left and right regional cerebral oxygen saturation (rSO_2). The bottom graph is the percent of time the patient spent with a blood pressure at each 5 mmHg bin. The right and left COx data in the middle two graphs represent the correlation between regional cerebral oxygen saturation and mean arterial pressure. When mean blood pressure is in the autoregulation range, there is no correlation between regional cerebral oxygen saturation and blood pressure, represented by COx near zero. When blood pressure is outside the limits of autoregulation, regional cerebral oxygen saturation and blood pressure are correlated or cerebral blood flow is pressure passive. In this example, a mean blood pressure > 60 mmHg would ensure that blood pressure is above the lower limit of autoregulation. An upper limit of autoregulation is also demonstrated at a mean blood pressure of approximately 90 mmHg.

NIH-PA Author Manuscript NIH-PA Author Manuscript NIH-PA Author Manuscript