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Recent Advances in Application of Cerebral Oximetry in Adult Cardiovascular Surgery

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Cerebral oximetry is a noninvasive technology that continuously monitors cerebral tissue oxygen saturation, which is a sensitive index of global cerebral hypoperfusion. On the basis of near-infrared spectroscopy technology, information is provided on the availability of oxygen in brain tissue at risk during numerous pathological conditions. Complementary to the arterial oxygen saturation measured by pulse oximetry, cerebral tissue oxygen saturation reflects regional cerebral metabolism and the balance of local cerebral oxygen supply/demand. Recently, patient management with the guidance of cerebral oximetry has resulted in improved patient outcomes. This review will briefly describe the physics behind cerebral oximetry and will provide an overview of the literature focusing primarily on articles published within the past 5 years.

Keywords: NIRS; cardiac surgery; cerebral oximetry

Cerebral oximetry, based on near-infrared spectroscopy (NIRS) technology, provides information on the availability of oxygen in brain tissue at risk during numerous pathological conditions.[1] Cerebral oximetry measures regional cerebral tissue oxygen saturation ($SctO_2$) at the microvascular level (arterioles, venules, and capillaries only).[2-4] Complementary to the arterial oxygen saturation (SaO_2) measured by pulse oximetry, $SctO_2$ reflects regional cerebral metabolism and the balance of local cerebral oxygen supply/demand. The advantages of cerebral oximetry are: (1) it provides $SctO_2$ values continuously and noninvasively at the bedside,[5] and (2) $SctO_2$ is a sensitive index of cerebral hypoxia and/or cerebral ischemia,[6] which is one of the main causes of brain injury in clinical settings.[7]

Cerebral oximetry, otherwise know as NIRS, is the subject of many reviews.[1,5,8] In one of the most recent papers, Taillefer and Denault[9] systematically reviewed the clinical efficacy of cerebral oximetry monitoring in adult cardiac surgery. On the basis of reviews of publications dated pre-January 2004, they concluded that further investigation is needed to prove the clinical utility of NIRS in cardiac surgery. In the past few years, there have been new advances in NIRS technology and in clinical studies of cerebral oximetry in adult cardiovascular surgery. This review will focus on these recent developments and our experiences with cerebral oximetry monitoring during adult cardiovascular surgery at our institution.

The Significance of Cerebral Oximetry Monitoring for Cardiovascular Surgery

Monitoring brain oxygenation is critical in providing information to guide patient management in many clinical situations.[10,11] Currently, brain oxygenation can be measured invasively by jugular bulb oximetry ($SjvO_2$) or brain tissue Po_2 sensor.[12,13] However, these modalities are invasive and difficult to use. Therefore, a bedside cerebral oximeter that can provide noninvasive measurement of cerebral oxygenation is highly desirable.

Despite a decline in the overall mortality after coronary artery bypass grafting (CABG) and valvular surgery with cardiopulmonary bypass (CPB), the rates of cognitive dysfunction have not improved.[14] In some reports, most patients had subtle signs of impaired

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cognitive performance, with incidences ranging from 60% to 80%.[15] There are 2 different forms of brain injury that may occur after CABG or thoracic aorta surgery: neurological dysfunction (ND) and neurocognitive dysfunction (NCD). The ND is defined as clinically evident focal or global neurological injury resulting in stroke, hypoxic encephalopathy, transient ischemic attack, or stupor. The NCD is defined as postoperative confusion, agitation, delirium, prolonged obtundation, or transient Parkinsonism. The NCD occurs more frequently, affecting 40% to 80% of CABG or aortic surgery patients, depending on the method of detection used.[16] Although it is easy to diagnose postoperative ND, NCD is more subtle and needs to be evaluated with a full battery of neurocognitive testing administered by trained professionals. Recent reports based on accurate neurocognitive testing before and after surgery have suggested that NCD can no longer be considered a benign self-limiting condition but rather a long-lasting neurocognitive insult capable of reducing quality of life by impairing memory and fine motor function.[17]

The etiology of brain injury following cardiac surgery is still not completely understood and is somewhat controversial. Some of the possible mechanisms include diffuse microembolization, cerebral hypoperfusion, and metabolic factors. The incidence of injury seems to be higher when CPB duration exceeds 70 minutes and when there is rapid rewarming, particularly in the older surgical population.[18] Regardless of the immediate cause, such persistent cognitive dysfunction likely results from brain ischemia during surgery, which may be a result of focal arterial embolism,[19] global hypoperfusion of the brain,[20] or an interaction of the 2.[21]

Strategies for preventing arterial embolism and brain hypoperfusion differ. To avoid arterial embolism during CPB, arterial line filters, intraoperative imaging, and careful manipulation by the surgeon are essential. However, diffuse hypoperfusion of the brain can be avoided only by very careful planning; if something goes wrong, the only hope is early detection and immediate restoration of adequate perfusion before irreversible brain damage develops. For this purpose, sensitive, real-time monitoring of brain ischemia during such surgical procedures is needed.[22] At the present time, cerebral oximetry can fulfill this role as the only feasible technology that monitors cerebral hypoxia and/or cerebral ischemia noninvasively and continuously.

The Evolution of Cerebral Oximetry

The idea of using NIRS to measure cerebral tissue oxygenation noninvasively was first introduced by Jobsis in 1977.[23] The principle of NIRS is based on the known fact that near-infrared light passes through skin and skull readily and is absorbed by certain biological molecules in the brain.[24,25] The NIRS measures oxygenation in biological tissue mainly at the microcirculation level (capillaries, arterioles, and venules) based on different absorption characteristics of the chromophores oxyhemoglobin (Hbo_2) and deoxyhemoglobin (Hb) in the near-infrared spectrum. A "biological spectroscopic window" exists at the wavelength range 660 to 940 nm because only a few chromophores like Hb and Hbo_2 strongly absorb light in this spectra range, allowing light to penetrate tissue to a great distance. In this wavelength range, absorption of light due to other biological compounds and tissues, such as water, lipids, skin, and bone, is lower in magnitude, and these biological compounds generally have a flat absorption spectra when compared with Hb and Hbo_2.

Over the years, many NIRS devices (cerebral oximeters) were developed by either research groups or commercial entities.[26-30] Early versions of NIRS monitors have limited capacity or suffer from poor performance. With the advances in optical and electronic technologies and by the improved understanding of the underlying basic theory and model of light propagation in biological tissue, NIRS has evolved to semi-quantitative devices[8] and finally to absolute quantitative instruments.

Technically, NIRS instrumentation implements continuous wave (CW), time domain (TD), or frequency domain (FD) technology[31,32] often combined with spatially resolved (SR)[33] methods. Most CW NIRS instruments measure changes in light absorption by recording the changes in the intensity of light both transilluminated through or reflected by photon scattering in tissue. The CW instruments usually do not measure the path length. Instead, path length is canceled out mathematically in oxygen saturation algorithms or is substituted with a predetermined average path length obtained from data collected by TD or FD instruments. The TD-type instruments measure the temporal response of tissue to an ultrashort input light pulse that lasts only for a few picoseconds. The temporal distribution of light emerging from the tissue surface is then

detected with a streak camera or photon counter.[34,35] The flight times relative to a reference pulse of individual photons are measured to obtain a histogram of the distribution of arrival times (temporal point spread function [TPSF]). By fitting the TPSF to a light transport model, values of absorption and scattering (μ_a and μ_s') can be calculated.[36] The TD-type NIRS instruments are considered to be more accurate, but they are large, expensive, and confined to dedicated optical laboratories. In the FD-type instrument, the light source is intensity modulated at radio frequencies (100~200 MHz). For light exiting the tissue, the light intensity *I*, phase shift Φ, and modulation depth *M* relative to the input signal are measured. By fitting the data to a diffusion model, the changes in chromophore concentrations can be calculated from attenuation changes.[37] The SR refers to a methodology used in some NIRS devices by measuring intensity changes at multiple light sources and detector spacings. The SR devices use the gradients of the optical signal from this multidistance measurement to quantify the NIRS parameters.[37]

Regardless of the type of methods applied, a NIRS instrument comprises the means to deliver infrared light to the object under study and the detecting means to collect the light after it propagates through the object. For a clinical NIRS monitor, the challenges center around the key components, which are (a) the optical probe that is easily attached to the object and is able to safely deliver energy to the object under study, as well as to collect the very low-intensity energy after it propagates through the object; and most of all, (b) the algorithm that processes the received signals and calculates the NIRS parameters.

At present, there are only a few cerebral oximeters commercially available. Of these, only 2 companies have food and drug administration (FDA) clearance to market cerebral oximeters in the United States.

INVOS (Somanetics Corporation, Troy, Michigan)

The INVOS cerebral oximeter has been commercially available for over 10 years.

The INVOS uses 2 wavelengths of infrared light (730 and 810 nm) from light-emitting diodes (LEDs).[38] This device has 2 channels for bilateral brain monitoring. The INVOS has disposable sensors, which contain LEDs and 2 light detectors at fixed distances from the light source (3 and 4 cm for adult sensor). The INVOS uses an SR algorithm assuming that there is no wavelength dependence of scattering and that there is linearity over the 1 cm between the 2 detectors.[39] The device calculates and displays the value of regional cerebral oxygen saturation (rSO_2). According to the FDA "Indications for Use," the INVOS only provides trend monitoring of regional hemoglobin oxygen saturation of blood in the brain of an individual.[29] This means that clinical intervention should be based on changes of rSO_2 from the initial baseline value, which is usually obtained at preinduction of anesthesia. In other words, the value of rSO_2 from the INVOS cerebral oximeter should be viewed with caution if the preinduction value is unknown. In fact, because we use cerebral oximetry routinely in cardiac surgery cases, the author has personally observed events during which the rSO_2 value of the INVOS was in the thirties (which is consider gravely low[40] if taken as an absolute value) in alert patients at preinduction.

Trend-only cerebral oximetry may be inadequate. Some studies suggest that perioperative management can be modified based on the application of trend-only cerebral oximetry. Because these monitors measure trends only, a baseline has to be established first, and cerebral oximetry values need to be maintained at or near the preoperative baseline.[41,42] Another approach is to keep the cerebral oxygen saturation at levels within 20% to 25% of the anesthesia preinduction value.[43,44] However, studies have shown that 75% of patients undergoing CABG have a significant impairment in baseline regional cerebral perfusion (rCP).[45] Other studies also demonstrated that patients undergoing cardiovascular surgery have a high prevalence of cerebral vascular disease in varying degrees.[46] In addition, abnormal preoperative rCP was found to be a strong indicator for postsurgical decline in neuropsychological testing.[47] These findings suggest that it is difficult to define a normal preinduction baseline value for the trend-only cerebral oximetry. A percentage drop based on the unreliable baseline value is more questionable to serve as a threshold for clinical intervention. In fact, studies have confirmed that although a trend-only cerebral oximeter can detect adverse brain oxygenation by measuring the change in rSO_2 from a baseline value, it cannot provide accurate, reliable, normal, and threshold values of $SctO_2$.[48-54]

FORE-SIGHT (CAS Medical Systems Inc, Branford, Connecticut)

The FORE-SIGHT absolute cerebral oximeter is a new device that has recently emerged in the market.[55]The FORE-SIGHT monitor was developed with research grants from the National Institute of Neurological Disorders and Stroke of the National Institute of Health (NIH).[56] The FORE-SIGHT monitor is a continuous wave, spatially resolved, near-infrared spectrometer that measures absolute cerebral tissue oxygen saturation ($SctO_2$%). This device has 2 channels for bilateral brain monitoring. The disposable sensor has a light source composed of a fiber optic light guided from the monitor with a prism and 2 light detectors (scalp and brain) at fixed distances (1.5 and 5 cm) from the light source. The scalp detector samples returning light from the extracranial tissue, whereas the brain detector samples returning light signal from both the brain and the extracranial tissue. The signal from the scalp detector is used to cancel extracerebral interference from the signal of the brain detector to obtain information that mostly comes from the brain. Laser light at an FDA-deemed safe level (Class I laser) is projected into the brain in 4 precise (bandwidth < 1 nm) wavelengths (690, 780, 805, and 850 nm) to capture information needed for the algorithm to calculate the absolute value of $SctO_2$. From the NIH funded research,[56] it was determined that 4 precise wavelengths are needed to maximize the measurement accuracy of oxyhemoglobin and deoxyhemoglobin in determining absolute $SctO_2$, by compensating for wavelength-dependent scattering losses and by accounting for interference from other background light absorbers[57] (such as fluid, tissue, and skin pigmentation). Because the FORE-SIGHT provides an absolute value of $SctO_2$, it is possible to establish threshold values for $SctO_2$ to guide clinical interventions. Furthermore, no preinduction baseline measurement is needed for obtaining meaningful readings.

FORE-SIGHT absolute cerebral oximeter determined $SctO_2$ is defined as the ratio of concentrations of Hbo_2 to $Hb + Hbo_2$ in the brain tissue. The value of $SctO_2$ reflects a proportional mix of arterial and venous blood, which was validated from arterial and internal jugular venous blood.[58] It is estimated that the NIRS cerebral oximeter interrogated brain tissue microvasculature is approximately 70% venous and 30% arterial during most physiological conditions in humans based on the positron emission tomographic studies.[59]

In validation studies, FORE-SIGHT–determined $SctO_2$ showed a strong correlation with invasive blood samples over the spectrum of pulse oximeter–determined arterial oxygen saturation (SPo_2) values between 70% and 100% from healthy volunteers.[60,61] The bias and precision (standard deviation [SD] = 1) for the FORE-SIGHT $SctO_2$ compared with reference $SctO_2$ derived from co-oximetry of arterial and jugular bulb blood samples was 0.18 ± 3.7 (SD = 1). It is clinically accepted that $SjvO_2$ has a normal lower safe limit of ~45%.[62,63] The FORE-SIGHT $SctO_2$ is approximately 10% higher than $SjvO_2$ over a wide range of oxygen saturation values. Therefore, the absolute FORE-SIGHT cerebral oximeter lower safe $SctO_2$ threshold is estimated to be approximately 55%.

MacLeod et al[64] published an abstract containing the initial results of the FORE-SIGHT study on cardiac patients. In all, 33 patients presenting for CABG and/or valvular surgery were included. The median $SctO_2$ value in patients prior to induction was 70% with small variability (SD = 4.1%). This preinduciton $SctO_2$ value was independent of age, race, or sex. After initiation of CPB, a decrease in $SctO_2$ was seen (65 ± 5%), but eventually $SctO_2$ recovered to close to preinduction values by the time of chest closure (68 ± 5%). Interestingly, patients undergoing valve procedures had lower $SctO_2$ values for longer duration while on CPB.

Fischer et al[65] presented preliminary results of the use of the FORE-SIGHT as a monitor of cerebral oxygenation during aortic surgery with deep hypothermic circulatory arrest. The postinduction $SctO_2$ was 68.5 ± 6%. After the initiation of CPB and cooling of the patient, the $SctO_2$ value increased in most patients ($84\% \pm 4.9$%). The rate of $SctO_2$ increase matched the rate of core cooling. After initiation of circulatory arrest, a decline in $SctO_2$ was seen (59 ± 8.9%). After reestablishing cerebral perfusion, the $SctO_2$ values quickly returned to prearrest levels.

Applications of Cerebral Oximetry Monitoring

Two of the main areas of interest for the clinician are the ability of the device to predict a catastrophic event and to have a direct positive effect on clinical outcome. Both of these goals are ambitious, and the outcome goal is particularly difficult to prove. However, studies are emerging revealing that optimization of $SctO_2$ improves overall morbidity and decreases

hospital length of stay. The latter endpoint is appealing not only to patients and their physicians but also to hospital administrators and society in general.

Catastrophic Events Avoidance

The discipline of anesthesiology is frequently compared with that of aviation. Both fields are historically viewed by the layman as extremely dangerous. However, with advances in science and safety algorithms occurring over the course of the past decades, both anesthesiology and aviation have become extremely safe. Unfortunately, despite rigorous training and numerous checklists, unexpected catastrophic events still occur. Cerebral oximetry adds an additional safety check for the clinician during the perioperative period. Catastrophic events that may occur during the course of surgeries, which would otherwise have gone unrecognized resulting in permanent damage or death, can now possibly be identified early enough for corrective measures to be implemented. The author will review the literature and describe his own experiences regarding the catastrophic events that could be avoided by the continuous monitoring of $SctO_2$.

Most reports regarding catastrophic events are case studies focused around the pediatric population. Rodriguez et al[66] and Sung and Chong[67] reported on the utility of cerebral oximetry to detect superior vena cava obstruction caused by malpositioned venous cannulae. In addition to cerebral oximetry, Rodriguez et al[66] used transcranial Doppler and electroencephalographic (EEG) monitoring. During upper venous congestion, all monitoring modalities revealed pathological values. However, the report of Sung and Chong[67] relied solely on cerebral oximetry to detect venous cannula malpositioning. A severe decline reading cerebral oximetry and plethora of the face were the only 2 signs of an ensuing catastrophic event. All other physiological values (eg, blood pressure, Pao_2, and $Paco_2$) were normal.

Yeh and Austin[68] reported on the use of a multimonitoring approach to detect catastrophic neurological events. During the fenestration phase of a Fontan procedure, air was accidentally entrained into the systemic circulation. An acute deterioration in the readings of transcranial Doppler, cerebral oximetry, and EEG monitoring was detected. Corrective interventions were swiftly implemented. No neurological sequelae resulted from the air embolism.

Orihashi et al[69] report on the utility of cerebral oximetry to detect malpositioned cerebral perfusion catheters used during selective antegrade cerebral perfusion for aortic arch repair. In 4 of 35 consecutive cases, a malpositioned catheter could be detected by an unexplained decline in cerebral oximetry.

Similar use of cerebral oximetry regarding correct placement of cerebral perfusion catheters is mentioned by Hagl et al[70] in a detailed review of different perfusion and monitoring techniques used during hypothermic circulatory arrest.

At the author's institution, 2 catastrophic events were first detected by the FORE-SIGHT absolute cerebral oximeter. A patient presenting for aortic arch surgery revealed an unusual $SctO_2$ pattern shortly after CPB was initiated. A sharp decline in $SctO_2$ (40%) was observed despite cooling to 20°C. Echocardiography monitoring indicated that the low $SctO_2$ value seen in this patient might have been caused by air emboli. The surgeon was informed, and the field was submerged with saline. The source of air entrainment was believed to originate from a left ventricular vent entering the upper right pulmonary vein. The insertion site was snared down with a purse-string suture. Subsequent air entrainment could not be identified thereafter. This patient was extubated on postoperative day 5 (compared with an average extubation time of 1 or 2 days) due to severe confusion and lack of orientation to time, place, or person. Long-term neurological follow-up evaluation for all patients is pending.

A second case in which cerebral oximetry gave the clinician an early warning sign was during an elective Bentall procedure. During the rewarming phase, after completion of the procedure, a sudden unexpected drop in $SctO_2$ was detected ($SctO_2$ 53%, Figure 1). An arterial blood gas analysis revealed respiratory alkalosis ($Paco_2$ 26 mm Hg). The cerebral desaturation was due to hypocapnia, which led to cerebral vasoconstriction and hypoperfusion. The event occurred because mechanical ventilation was commenced without decreasing the fresh gas delivery to the membrane oxygenator of the cardiopulmonary bypass circuit while still on partial CPB. As soon as it was recognized and the respiratory derailment corrected, $SctO_2$ promptly returned to the normal values. No neurological sequelae resulted from this intraoperative event.

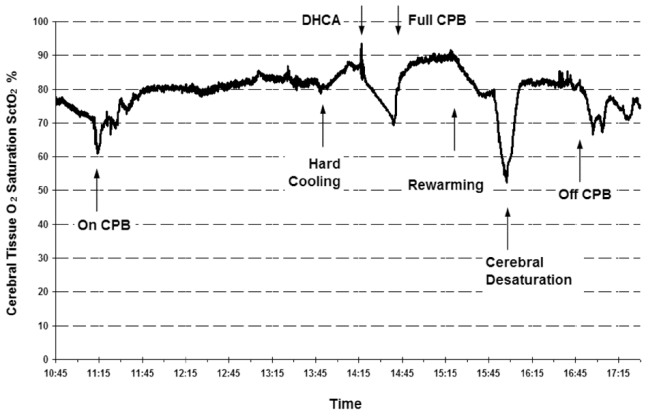

Figure 1. An event of cerebral desaturation due to hypocapnia was quickly recognized with cerebral oximetry monitoring (FORE-SIGHT).
The event occurred because mechanical ventilation was initiated without decreasing the fresh gas delivery to the membrane oxygenator of the cardiopulmonary bypass circuit while still on partial cardiop**ulmon**ary bypass. $SctO_2$ indicates cerebral tissue oxygen saturation; DHCA, deep hypothermic circulatory arrest; CPB, cardiopulmonary bypass.

Tailored Patient Management

An increasing number of evidence is mandating the need for a tailored patient management protocol. Current approaches for managing pump flow, arterial blood pressure, and pH during the cardiac surgery are based on studies that included a few elderly or high-risk patients and predated many other contemporary practices.[71] For example, watershed-distribution stroke happens more frequently in patients undergoing cardiac surgery than in the general stroke population (over 40% vs 2%-5%, respectively).[72-74] Gottesman et al[75] reported that the mechanism of watershed stroke after cardiac surgery may include an intraoperative decline in blood pressure from a patient's baseline. This suggests that following a standard protocol to maintain blood pressure at a predetermined value during cardiac surgery is insufficient for some patients. Real-time cerebral oximetry is capable of evaluating the effects of blood pressure and perfusion changes to cerebral oxygenation. Therefore, cerebral oximetry can be used for this tailored patient management approach.

A growing body of literature is emerging that demonstrates improved outcomes in patients in whom cerebral tissue oxygenation was monitored and optimized. In a large, nonrandomized study of patients undergoing cardiac surgery, Goldman[41] reported that the treatment group using cerebral oximetry monitoring to maintain regional cerebral oxygen saturation (rSO_2, INVOS, Somanetics) values at or near the patient's preinduction baseline demonstrated a significantly lower incidence of permanent stroke[67]. The weakness of this study is its nonrandomized and retrospective design. The control group consisted of a historical cohort. Patients who underwent cardiac surgery 18 months prior to the introduction of cerebral oximetry at the author's institution were subsequently compared with the treatment group consisting of patients who underwent cardiac surgery the following 18 months. Additionally, the author acknowledges that they were unable to determine how close rSO_2 values were maintained to baseline values during the course of surgery. Despite these shortcomings, one could argue, as the author pointed out, that better compliance with a predefined target value would translate into potentially better outcomes. The fact that the study group consisted of patients with more comorbidities, yet had a lower incidence of permanent stroke; decreased need for prolonged ventilation; and shorter length of hospital stay is impressive.

Murkin et al[76] published an article in January 2007 that corrected many of the shortcomings of the Goldman[41] paper. A randomized, blinded study of 200 CABG patients demonstrated prospectively that rSO_2 (INVOS, Somanetics) monitoring is associated with a significant improvement in overall outcome after cardiac surgery. Murkin utilized an intraoperative management protocol designed to maintain rSO_2 values at or above 75% of the preinduction baseline. The results were associated with a significant improvement in overall organ function and decreased postoperative length of stay. Fewer patients suffered a stroke in the intervention group compared with patients in the control group. However, a significant reduction in stroke rate could not be seen due to underpowering of the study. Nevertheless, the fundamental hypothesis that cerebral oxygenation could be used as a surrogate marker for systemic perfusion and improvement in clinical outcome was supported by the results of this study.

Orihashi et al[77] showed in an observational study examining 59 consecutive patients presenting for aortic surgery using selective cerebral perfusion (SCP) that a sustained decrease in rSO_2 (TOS-96, Tostec CO, Tokyo, Japan) was observed in patients with infarcts, suggesting hypoperfusion as the etiology. Transient neurological events occurred more

frequently in patients with sustained drops below 55% for over 5 minutes. Recommendations were made that a decline in rSO_2 below 55% should be addressed without delay.

In another randomized, prospective study of elderly patients undergoing major abdominal surgery, Casati et al[78] reported on improved mini mental scores (MMS), more rapid post anesthesia care unit discharge, and shortened length of hospital stay in 122 geriatric patients after major abdominal surgery in which cerebral oximetry was monitored and optimized. Although the utilization of the MMS to address postoperative cognitive impairment is crude, this study did demonstrate that 20% of all patients experienced a decrease in rSO_2 (INVOS, Somanetics) below 75% of baseline without any change in systemic oxygenation (SPo_2).

Our experience with the FORE-SIGHT absolute cerebral oximeter also demonstrated that this device can be used as a guide for patient management during cardiac surgery. Fischer et al[79] reported an unexpected $SctO_2$ pattern in a patient presenting for repair of an ascending aortic aneurysm. Despite uneventful hemodynamic management (mean arterial pressure [MAP] 50 mm Hg) on CPB a steady decline in $SctO_2$ was observed. Postoperative analysis showed that unlike other patients who have normal patterns of $SctO_2$ (Figure 2), in this patient, $SctO_2$ variation corresponded to dynamic fluctuations of mean arterial pressure MAP (Figure 3). This suggests that the failure of $SctO_2$ to rise with cooling was attributed to the loss of cerebral autoregulation. These findings indicate that hemodynamic management on CPB needs to be tailored to the individual patient. Maintaining MAP at 50 to 60 mm Hg during hypothermic CPB is tolerated by most patients, but this level seems to be inadequate for certain patients.

However, not all studies have shown a positive correlation between cerebral oximetry monitoring and postoperative outcomes. Reents et al[80] report in an observational study of 47 patients undergoing CABG that no correlation could be found between intraoperative regional rSO_2 values as assessed by the INVOS 4100 device and early postoperative cognitive performance. Careful review of this study does alert the reviewer to flaws in its design. The author uses 2 cutoff points as markers for low cerebral perfusion, a decrease in rSO_2 values under 40% and/or a decrease of more than 25% from baseline values. The INVOS is approved as a trend-only cerebral oximeter. Therefore, expecting this device to identify an absolute value, which would represent a threshold correlating to poor postoperative outcomes, must be viewed as a methodological flaw. Additionally, the author defined baseline value as

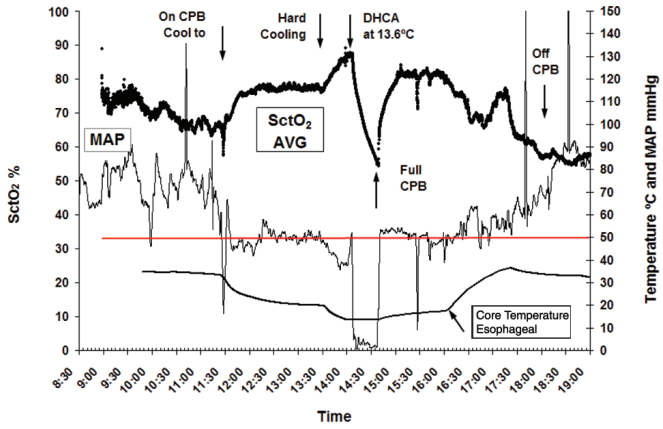

Figure 2. Normal pattern of $SctO_2$ of a patient undergoing aortic surgery with DHCA.
The $SctO_2$ increased with cooling to 20°C and increased further with hard cooling to 13°C. Fluctuation of MAP, which was maintained around 50 mm Hg, had no effect on $SctO_2$. $SctO_2$ indicates cerebral tissue oxygen saturation; DHCA, deep hypothermic circulatory arrest; MAP, mean arterial pressure; CPB, cardiopulmonary bypass.

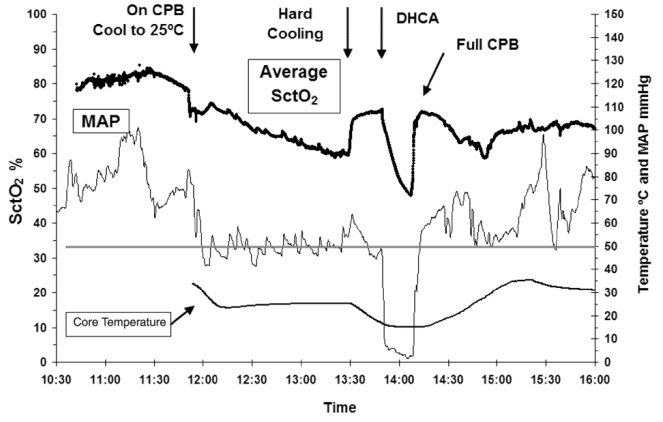

Figure 3. Observation of a steady decline in $SctO_2$ with cooling despite uneventful hemodynamic management (MAP 50 mm Hg) on cardiopulmonary bypass.
The $SctO_2$ variation corresponded to dynamic fluctuations of mean arterial pressure MAP, suggesting that the failure of $SctO_2$ to increase with cooling was attributed to the loss of cerebral autoregulation. $SctO_2$ indicates cerebral tissue oxygen saturation; MAP, mean arterial pressure; CPB, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest.

the value obtained after induction of general anesthesia and transfer of the patient from the induction room to the operating theater. A true baseline value should be obtained prior to the induction of anesthesia as was done in the Murkin[76] paper.

Summary

Cerebral oximetry has emerged as an exciting new technology that many cardiac anesthesiologists have incorporated into their monitoring standard of care. In the past, critics were quick to point out the lack of evidence positively linking the use of cerebral oximetry with patient outcomes. However, recent randomized prospective studies have confirmed the clinical efficacy of cerebral oximetry monitoring. As with any new technology, improvement in accuracy and reliability is an ongoing process. The past decade has seen tremendous advances in NIRS technology. The introduction of the FORE-SIGHT absolute cerebral oximeter in 2006 must be considered a groundbreaking achievement. Being able to measure absolute values of $SctO_2$ opens new possibilities for the clinician. Most importantly, it will now be possible to establish threshold values for $SctO_2$ to guide clinical interventions. Additionally, patients for whom a baseline value could not be established (intubated patients in emergency department or intensive care unit) can now profit from real-time cerebral oxygenation monitoring.

The past 5 years have seen the publication of well-designed studies clearly revealing that cerebral oxygenation, if monitored and optimized intraoperatively, can improve outcome and can shorten the hospital length of stay[76,79].

Although it is by no means the author's intent to endorse this technology solely on the basis of being an attractive concept, it must be stated that the overall risk to possible benefit clearly lies on the side of cerebral oximetry monitoring.

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