Inadequacy of Near-Infrared Spectroscopy Cerebral Oximetry Monitoring for Detecting Neurological Complication

Abstract

Near-infrared spectroscopy (NIRS) cerebral oximetry is an established and standard monitoring modality for surgery under extracorporeal circulation with circulatory arrest. It helps to reduce the neurological complication, but in many instances, it becomes not only technically challenging but also is difficult to interpret and take corrective action based on the NIRS values. In this case study, we aimed to present the inadequacy of cerebral oximetry for detecting neurological complication.

Keywords: *Aortic arch surgery, cerebral oximetry, near-infrared spectroscopy*

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Introduction

The concern for neurological outcome following cardiac surgery is a major issue. The actual challenge is to monitor and prevent deleterious factors from affecting the brain function. Cardiopulmonary bypass (CPB) is known to cause neurological impairment, and perfusion is one of the few modifiable risk factors. Cerebral oximetry assessed through near-infrared spectroscopy (NIRS) has been proposed as a "standard of care," and the technique is now widely used.[1] A major advantage of this technique is that it allows for noninvasive continuous monitoring of cerebral oxygenation. Algorithms have been described to treat patients with sustained low levels of regional cerebral saturation (rSO2), i.e., patients who are considered to be at risk for impaired neurological outcomes. However, there is little, if any, scientific proof of NIRS reliability in cardiac surgery or of clinical improvement following perioperative NIRS monitoring.[2,3] We present our clinical case in which the patient in spite of being monitored by cerebral oximetry with NIRS developed neurological complications. We used the Invos 5100C monitor (Somanetics, Covidien, Mansfield, USA) using SomaSensor disposable transducer capable of producing and detecting optical data from the patient.

Case Report

A 52-year-old (163 cm; 52 kg) male patient diagnosed with asymptomatic severe aortic stenosis (sclerodegenerative) in New York Heart Association Class II presented with a history of syncope. On general examination, the pulse rate was 98 per min, regular with blood pressure of 110/84 mmHg. On auscultation, S_2 was single with ejection systolic murmur Grade III/IV. Transthoracic echocardiography revealed severe calcific aortic valve (annulus 26 mm) with peak systolic gradient of 72 mmHg and mean of 43 mmHg, mild aortic regurgitation, concentric left ventricular hypertrophy with 55% ejection fraction, and mild mitral regurgitation. Aortic angiography showed fusiform aneurysmal dilatation of the ascending aorta and arch of aorta to the origin of the left subclavian artery [Figure 1]. Carotid Doppler showed normal bilateral carotids with no significant block or atheroma. In preanesthetic assessment, all laboratory investigations were normal, blood pressure was 112/86 mmHg, and heart rate was 84 beats/min. He was accepted in the American Society of Anesthesiologists physical Grade IV under General Anaesthesia for Bentall debranching procedure.

Preinduction monitoring included electrocardiogram, pulse oximetry, bispectral index, and invasive blood pressure in the right radial and left femoral arteries. NIRS technique was used to

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measure cerebral oximetry. Two disposable SomaSensor transducers (Invos 5100C, Covidien, USA) capable of producing and detecting optical data from the patient were applied to the left and right sides of the patients' forehead. Femoral vein and femoral artery were dissected for emergency femorofemoral bypass. After induction of anesthesia and endotracheal intubation, transesophageal echocardiography (TEE) was performed using two-dimensional TEE probe to confirm the diagnosis and to detect any additional findings. No plaque was noted in ascending aorta, arch, and descending aorta in TEE. After heparinization, CPB was commenced using high aortic and two-stage right atrial venous cannulation. After replacing the aortic valve and suturing the proximal end of the tube graft, cannulas were placed separately for the right and left carotid artery for antegrade cerebral perfusion. The distal end of the aortic arch and the left subclavian artery was sutured under deep hypothermic circulatory arrest (DHCA) at 20°C. During DHCA, the antegrade cerebral perfusion through the right and left carotid artery was continued at a rate of 800–1000 ml/min. The institutional protocol for brain protection during DHCA was followed which also included external brain cooling, pharmacological protection in the form of injection thiopentone 3 mg/kg during cooling and rewarming, injection phenytoin sodium 15 mg/kg, injection methylprednisolone 30 mg/kg, and injection lignocaine 2 mg/kg. Total bypass time was 330 min, aortic cross-clamp time of 243 min and DHCA time of 37 min. Monitored parameters (invasive blood pressure mean, cerebral NIRS, temperature, and bispectral index [BIS]) in operation room and intensive care unit are shown in Figure 2. NIRS values were 72.9 ± 4 and 64.8 ± 4.9 for the left and right hemisphere, respectively. The values never changed more than 11% throughout the procedure.

The patient developed the right hemiparesis postoperative, confirmed with noncontrast computerized tomography head/magnetic resonance imaging which revealed the left middle cerebral artery territory stroke which was embolic [Figure 3]. He was managed conservatively and started recovering with supportive care. The patient was discharged from the hospital after 3 weeks with right hemiparesis.

Discussion

Regional cerebral O_2 saturation (rScO2) monitoring with NIRS was possible when it was shown that light in the near-infrared spectrum penetrates the skull allowing measurement of brain oxy-and deoxyhemoglobin concentrations. rScO2 monitoring for the adequacy of cerebral oxygenation and perfusion during cardiac surgery soon became popular. Self-adhesive pads applied to the skin of the forehead emit light in the near-infrared spectrum that is measured by sensors at 30 mm and 40 mm from the light-emitting diode in the INVOS 5100C monitor. The distance of the sensor from the light source determines the

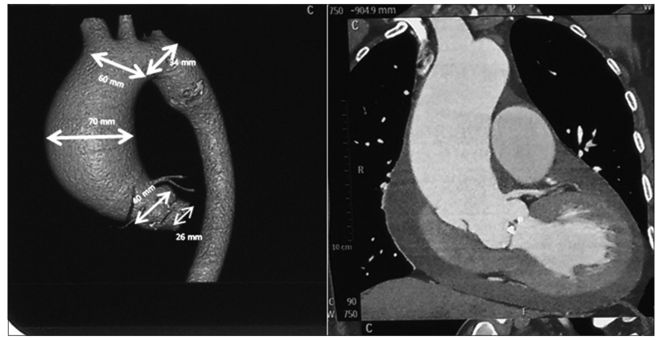

Figure 1: Computed tomography aortic angiography showing dilated ascending aorta and arch of aorta to the left subclavian artery

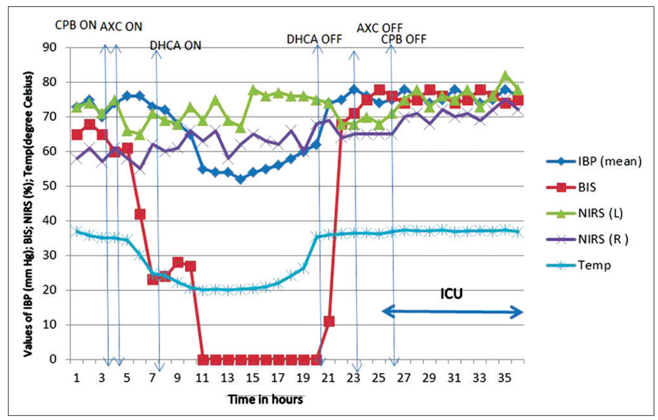

Figure 2: Monitored parameters (invasive blood pressure mean, cerebral near-infrared spectroscopy, temperature, and bispectral index) in operation room and intensive care unit

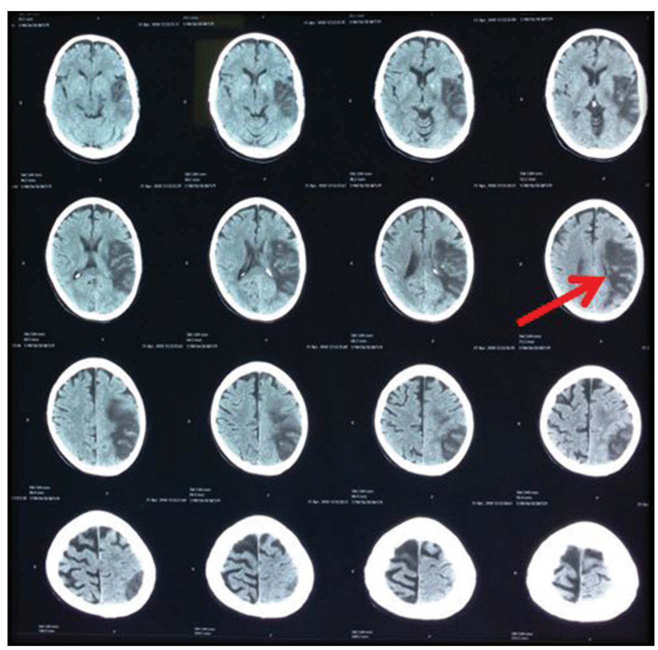

Figure 3: Noncontrast computerized tomography head, postoperative showing wedge-shaped hypodensity involving the left frontoparietal region suggesting left middle cerebral artery territory ischemic stroke

spatial resolution of the emitted light. Using the modified Beer-Lambert law, NIRS provides the measurement of the oxygenated hemoglobin in relation to total hemoglobin concentration. Devices use a proprietary algorithm for subtracting O_2 saturation from superficial tissue (i.e., bone and extracerebral tissue), from that obtained from deeper tissue to yield rScO2 value from the superficial frontal cortex. Since approximately 70%–80% of cerebral blood is venous blood, rScO2 provides an indicator of the balance between regional O2 supply and demand. However, different individuals may have different percentages of venous blood in the frontal lobe, which explains why rScO2 as measured using cerebral oximetry shows interindividual variability. Since the cerebral NIRS monitor based on continuous-wave technology is a trend monitor; change from baseline together with the clinical situation instead of the absolute value observed should be monitored.

It was also observed that though BIS values decreased zero throughout the DHCA period; however, NIRS values remained near normal. BIS decreased to 0 with deep hypothermia and rose again with rewarming. Deep hypothermic circulatory arrest affects the electroencephalography (EEG), with slowing and eventual burst suppression. Typically, the reduction in BIS is inversely proportion to the suppression ratio, which reaches 100% at 17°C. There are interindividual variations which suggest that the effect of brain temperature on the EEG and BIS vary from patient to patient.[4] This is like the variable effects of anesthesia on consciousness level, EEG, and BIS values. However, NIRS values do not vary much and provide adequate information regarding cerebral oxygenation and perfusion.

The duration of rScO2 <55% during aortic arch surgery with selective antegrade cerebral perfusion has been associated with postoperative neurologic events.[5] Patients with postoperative stroke are more likely to have a 65%–85% reduction from the baseline in rScO2.[6] Strokes were confirmed by computed tomography brain imaging to have occurred in the hemisphere with the rScO2 desaturation. Whereas a relationship between rScO2 reductions and these outcomes has been reported, the results have not been consistent.[7] NIRS cerebral oximetry has moderate sensitivity (60%) and low specificity (25%) in predicting clinically symptomatic cerebral ischemia in patients undergoing carotid endarterectomy.[8] Another confounding factor in the interpretation of cerebral oxygenation may be the amount of extracerebral contamination of the NIRS signal. The measures from the INVOS cerebral oximeter are significantly modified by changes in extracranial blood flow and oxygenation, and this interference may affect the reliability of monitoring in clinical practice. Overall, the sensitivity of NIRS measured cerebral tissue oxygenation for detecting intracranial and extracranial flow changes was 87.5% and 0%, respectively. The specificity for these measurements was 100% and 0%, respectively.[9]

Moreover, there is no universal definition of what decrement in rScO2 from baseline constitutes an abnormal finding during cardiac surgery. Both relative decreases in rScO2 from baseline (e.g., 20% decrease) and an absolute threshold rScO2 (e.g., <50%) have been used.[10] Additional case reports have suggested that some patients with normal rScO2 values actually suffer from hypoperfusion, while others with low rSO2 values are in normal states of cerebral perfusion.[11] It is important to note that cerebral oximetry is primarily applied to the upper forehead, unless the patient is bald, in which case the monitor can be applied to other parts of the head as well. Therefore, it is regarded as a regional monitor. However, evidence shows that cerebral oximetry can be sensitive to acute changes in blood flow in the middle cerebral artery when the monitor is applied to the upper forehead and the parietal regions of the head. This implies that cerebral oximetry primarily monitors the brain territory perfused by the anterior circulation or the internal carotid artery. NIRS samples only a limited anterior area of the brain, the maximal depth of which is about 30–40 mm. This observation confirms a limitation of NIRS for the diagnosis of cerebral ischemia. Moreover, hemodilution, transfusion, hypocapnia, and hypercapnia also lead to significant variations in cerebral oximetry.[11] Therefore, the variations in cerebral oximetry during the initial period of CPB with blood-free prime in patients are multifactorial.

There are various possible causes of cerebral infarct during cardiac surgery such as hypotension, atheromatous emboli, air embolism, or any other nongaseous microemboli. Various neuromonitoring could be employed for early detection of such events such as transcranial Doppler apart from NIRS, BIS, and EEG.

In conclusion, many reports in the literature suggest that reductions in rScO2 during cardiac surgery may provide an indication for mechanical mishaps related to CPB cannulas, particularly during aortic surgery, although most are anecdotal. The level of evidence linking decreased rScO2 during cardiac surgery to the postoperative neurologic complications is low. Further, our case shows rScO2 reflects only the oxygen saturation in the frontal lobe of the brain. However, NIRS role in cardiac surgery should not be underestimated; it is only the limitation which one needs to be aware about.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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