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NIRS: A Standard of Care for CPB vs. an Evolving Standard for Selective Cerebral Perfusion?

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Abstract: Cerebral oximetry monitoring using near infrared spectroscopy (NIRS) is a potentially important modality for detection of cerebral ischemia. Despite several studies showing improvements in patient outcome with applied NIRS for cardiac surgery, there has been steady but not yet widespread adoption of this technique. However, for patients undergoing aortic arch surgery—a procedure in which direct interruption of flow to cerebral vessels is an inherent risk—a majority of high-volume centers are using cerebral NIRS on a routine basis. This review examines the rationale and efficacy of such applied neuromonitoring and consider factors instrumental in modifying clinical practice in evolving standards of care. **Keywords:** near infrared spectroscopy, cardiac surgery, cardiopulmonary bypass. *JECT. 2009;41:P11–P14*

STANDARD OF CARE

A common definition of "standard of care" would indicate a diagnostic and treatment process that a clinician should follow for a certain type of patient, illness, or clinical circumstance, e.g., adjuvant chemotherapy for lung cancer is "a new standard of care, but not necessarily the only standard of care." In legal terms, it is the level at which the average, prudent provider in a given community would practice. It is how similarly qualified practitioners would have managed the patient's care under the same or similar circumstances. How does this relate to cerebral oximetry monitoring for cardiac surgery?

NEAR INFRARED SPECTROSCOPY: A STANDARD OF CARE FOR CARDIOPULMONARY BYPASS?

It has been estimated that cerebral oximetry monitoring is used in approximately two thirds of pediatric cardiopulmonary bypass (CPB) procedures in North America and ~25% of adult CPB procedures. In a survey by Wernovsky et al. (1) from 52 international pediatric heart centers, thought to manage >1000 neonates with hypoplastic left heart syndrome annually, it was indicated that 64% of sites indicated that they used near infrared spectroscopic (NIRS) cerebral oximetry "essentially always." (1) As such, for pediatric cardiac surgery, cerebral oximetry is widely used. For adult cardiac surgery, the majority of centers are not using NIRS routinely, but with several recent prospective studies having shown an improved outcome in both coronary artery bypass (CAB) surgery (2) and in adult patients undergoing non-cardiac general surgical procedures (3), it is likely that increasing utilization will be observed. Whether it will become standard of care for CPB in the near future will likely require larger multicenter studies. However, given that cerebral oximetry has recently been added as data fields for the Society of Thoracic Surgeons national database, its utilization in cardiac surgical procedures continues to evolve (4).

AN EVOLVING STANDARD FOR SELECTIVE CEREBRAL PERFUSION?

The utilization of cerebral oximetry for aortic arch procedures is much greater than for routine CPB likely because of the more obvious potential for cerebral ischemia. A variety of central nervous system (CNS) complications are manifest in patients after aortic arch surgery. In one series of 42 patients, the in-hospital mortality was 7.1%, stroke rate was 4.8%, and there were six episodes of transient neurologic deficit (14.3%) (5). In this study, the incidence of neuropsychometric deficit at 6 weeks ranged between 6/12 (50%) in patients who underwent deep

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hypothermic circulatory arrest (DHCA) and 8/10 (80%) in patients who underwent selective anterograde cerebral perfusion (SACP), whereas at 12 weeks, it was 6/16 (38%) in DHCA patients and 4/11 (36%) in SACP patients. The contribution of cerebral hypoperfusion to such CNS complications and the ability of continuous NIRS monitoring of cerebral tissue oxygenation to detect and optimize cerebral hypoperfusion in the setting of DHCA will be reviewed.

HYPOTHERMIA, ELECTROENCEPHALOGRAM, AND $SjvO_2$ MONITORING

During complex aortic arch repair, surgical access may require interruption of systemic perfusion for relatively protracted periods. Although moderate (25–30°C) and deep (<25°C) hypothermia remain a mainstay for cerebral and systemic protection, there is relatively little ability to monitor cerebral well being during such times because the electroencephalogram (EEG) becomes progressively attenuated below 25°C. Accordingly, cerebral NIRS has been advocated to understand some of the cerebral responses to deep hypothermia and as a means of monitoring and detecting onset of cerebral ischemia during DHCA (6,7). Although some groups monitor jugular venous oxygen saturation ($SjvO_2$) using retrograde cannulation of the internal jugular vein as an index of cerebral metabolic suppression during cooling, correlation has not been shown between $SjvO_2$ and cerebral NIRS during DHCA (8). This discordance is likely indicative of the fact that NIRS is a highly regional measure of cerebral cortical oxygen tissue saturation (rSO_2), whereas $SjvO_2$ reflects global cerebral mixed venous oxygen saturation and is thus reflective of global changes in oxygenation and, as such, potentially less sensitive to regional variation of perfusion homogeneity. Unlike $SjvO_2$, cerebral oximetry is non-invasive, bilateral, and is not subject to "wall-artifact," or interference with oximeter signal caused by catheter impingement against the vessel wall, and, as such, is more acceptable for routine clinical monitoring.

RETROGRADE VS. ANTEROGRADE CEREBRAL PERFUSION

In addition to DHCA, some centers use retrograde cerebral perfusion (RCP) through the superior vena cava or, increasingly, SACP through the innominate or subclavian artery in attempts to extend the safe duration of circulatory arrest. There have been a variety of case reports of the ability of cerebral NIRS to detect onset of cerebral ischemia during aortic arch surgeries, and there is growing interest in the role of cerebral NIRS as a measure of adequacy of perfusion in this setting (9–12). Although RCP may provide additional cooling and may act to minimize cerebral embolization during circulatory arrest (13)—factors that likely explain the success seen by some groups using this technique—there is recognition that RCPs provide <10% of anterograde cerebral blood flow as determined in both a swine model and a study in non-human primates (14,15). This has been reflected in lower rSO_2 values seen during clinical NIRS monitoring in RCP vs. SACP (16,17). Although clinical outcomes are variable, several large experiential reviews have concluded that, for an extended interval, SACP seems to result in lower risk of CNS injury (18,19).

ISCHEMIA, NIRS, AND SELECTIVE ANTEROGRADE CEREBRAL PERFUSION

In assessing the role of NIRS monitoring during SACP, a study was undertaken in 46 consecutive aortic arch surgery patients in whom SACP was established by perfusion of the right subclavian artery (with or without left carotid artery perfusion) or by separate concomitant perfusion of the innominate and the left carotid arteries. In this study, bilateral regional cerebral tissue oxygen saturation index was monitored using INVOS 4100 NIRS (Somanetics Corp., Troy, MI), and the study used stroke as the primary clinical end point along with indices assessing the diagnostic performance of the NIRS device (20). Six patients died in hospital, and six patients (13%) experienced a perioperative stroke. In patients with stroke, regional cerebral tissue oxygen saturation values were significantly lower during SACP, and rSO_2 also tended to be lower in the affected hemisphere. Their analysis indicated that, during selective antegrade cerebral perfusion, regional cerebral tissue oxygen saturation decreasing to between 76% and 86% of baseline had a sensitivity of up to 83% and a specificity of up to 94% in identifying individuals with stroke. In their assessment, it was concluded that monitoring of regional cerebral tissue oxygen saturation using NIRS during SACP allows detection of clinically important cerebral desaturations and can help predict perioperative neurologic sequelae, supporting its use as a non-invasive trend monitor of cerebral oxygenation (20). In another study of 59 DHCA patients managed with SACP, it was reported that a sustained drop in cerebral rSO_2 below 55% correlated with transient neurologic events, but NIRS was limited for detection of embolic events or hypoperfusion in the basilar region (10).

CEREBRAL MALPERFUSION

In adult patients during aortic arch and minimal access surgery, cerebral malperfusion can occur either as a consequence of ascending aortic dissection with occlusion of carotid lumen (21,22) or because of migration of the

aortic endoclamp cannula during minimal access cardiac surgery with potential compromise of cerebral perfusion (23). During DHCA with SCP, cerebral ischemia can occur because of kinking or obstruction of the perfusion cannula during selective cerebral perfusion for circulatory arrest procedures—an event that has been documented during slightly >10% of such procedures (24).

There are increasing reports that bilateral rSO_2 monitoring can detect contralateral desaturation during unilateral selective cerebral perfusion. This can result from an incomplete circle of Willis, which in some series has a prevalence of up to 50% and has been estimated to be a factor in cerebral malperfusion in ~15% of patients (25,26). In a more recent case report, cerebral rSO_2 monitoring was used during selective cerebral perfusion in the absence of systemic CPB during repair of traumatic aortic arch rupture and detected both episodes of cerebral malperfusion and, most critically, acute thrombosis of carotid artery graft, leading to thrombectomy and restoration of flow (27). Therefore, the ability of INVOS cerebral oximetry to detect onset of critical levels of cerebral hypoperfusion is well attested and may be expected to play a critical role in up to 10–15% of such patients.

NIRS AND SPINAL CORD MONITORING

There are also some intriguing laboratory and clinical data that NIRS oximetry can also detect spinal cord ischemia during descending aortic repair. In a swine model in animals of up to 70 kg, sequential ligation of segmental spinal arteries produced progressive decrease in transcutaneous rSO_2 associated with histologic evidence of spinal cord ischemia (28). In a related case report, in a 6.8-kg infant undergoing surgical repair of congenital heart disease with complex cardiac and vascular anatomy, simultaneous NIRS monitoring of the oxygenation status in the brain and the right upper thigh showed lower torso ischemia caused by accidental cross-clamping of a hypoplastic descending aorta, which would otherwise have been unnoticed (29). These studies are preliminary, however, and further studies need to be done to assess the sensitivity and specificity of transcutaneous spinal NIRS to detect intraoperative cord ischemia and to determine whether NIRS monitoring can be used to guide therapeutic interventions.

SUMMARY

In addition to widespread utilization in pediatric cardiac surgical procedures, the ability to monitor the adequacy of cerebral oxygen saturation during aortic arch procedures with a view toward minimizing ischemic brain injury and adverse CNS sequelae is an important application for cerebral NIRS that is being increasingly adopted by large centers performing aortic arch surgery. In a recent (2006) Aortic Symposium, ~33% of participants indicated they routinely used cerebral oximetry monitoring (30). There is also preliminary evidence that NIRS monitoring may have a further role in the detection of spinal cord ischemia. If borne out in larger clinical trials, these applications have the potential to significantly improve patient outcomes.

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