



Near-infrared spectroscopy in adult cardiac surgery: between conflicting results and unexpected uses

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Neurological complications after cardiac surgery, ranging from permanent stroke to transient dysfunction, represent a key issue in the management of geriatric patients. Many patients aged 70 or more have history of neurological dysfunctions, which increases the risk of complications and sequelae.^[1–3] Severe neurologic diseases, such as strokes, occur in up to 6% of patients undergoing cardiac surgery.^[4] Therefore, in the setting of fragile patients, prevention is more important than treatment. There are several intraoperative mechanisms of neurological injury, such as embolism, inflammation, intraoperative anemia, carotid or intracranial artery disease, but hypoperfusion appears to be the final common pathway of cerebral damage.^[5] Many systems to monitor cerebral oximetry and allow physicians to restore an adequate cerebral perfusion have been developed over the years. Among these, near-infrared spectroscopy (NIRS) has been extensively investigated and currently represents the non-invasive real-time tool to monitor the oxygen content of cerebral tissue during adult cardiac surgery. However, its effectiveness is highly debated, since current studies lead to controversial results.^[6] The existing literature raises four major questions:

1. Why current studies about NIRS are contradictory?
2. Can NIRS be useful to monitor brain damage?
3. Can NIRS be useful to monitor other damages?
4. Can NIRS be useful in the outpatient clinic?

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1 Why current studies about NIRS are contradictory? “Variability”.

NIRS is based on cerebral oxygen saturation, and the first issue of many clinical studies is the lack of consensus in the threshold of cerebral oxygenation that results in a significant desaturation in the setting of cardiac surgery. Many pioneering studies were performed in vascular surgery and tilt-table tests, and a reduction of 20% from baseline or saturation absolute values less than 54%–56% were initially considered significant in patients undergoing carotid endarterectomy;^[7,8] however, the direct translation of those results in cardiac surgery is not applicable due to differences in anesthesia, the presence of cardiopulmonary bypass, and the effect of non-physiological blood flow. Retrospective and observational studies in cardiac surgery tried to define threshold values by evaluating patients with adverse neurological outcomes,^[5,9–11] and a reduction of 30% from baseline or saturation absolute values less than 40% were associated with clinical dysfunction. Two prospective trials in patients undergoing coronary artery bypass grafting (CABG) lead to different results, since Slater, *et al.*^[12] considered as significant a saturation absolute value less than 50%, while Murkin, *et al.*^[13] concluded that a reduction of 30% from baseline was significant, and the duration of hypoxia also played a pivotal role.

In general, the variability in the definitions of desaturation threshold does not allow to compare studies, and this is amplified by the variability of NIRS devices and anesthesiologic techniques used during cardiac surgery and cardiopulmonary bypass. In fact, the available NIRS devices have differences in the technical aspects of the emitted light and in the algorithms of computation. Other factors might interfere with NIRS, such as skull thickness, extracranial tissue saturation, anemia or sensor position.^[14] Also, impaired

cardiac output, pulmonary disease and previous cerebral vascular disease might reduce cerebral oxygen supply and results in low baseline saturation levels, and a further reduction might be differently tolerated by different patients.^[15] It has been also argued that NIRS can provide normal values of saturation in brain-dead patients and during autopsies;^[16–18] also, sensors might be positioned over areas of a previous stroke or scar after head injury, thus producing unreliable results in that area or being unable to detect hypoperfusion in other cerebral areas (such as brain stem).^[19]

2 Can NIRS be useful to monitor brain damage? Not yet.

In a systematic review, Zheng, *et al.*^[20] evaluated 43 studies and concluded that the evidence linking cerebral desaturation with postoperative neurological complication was low, thus not supporting routine cerebral oxygenation monitoring in cardiac surgery. In fact, considering the lack of consensus about desaturation threshold and the small sample size of many studies, with very few patients with stroke or other major neurological injury, it was not possible to support an association between cerebral desaturation measured using NIRS and adverse outcomes.^[21]

However, NIRS can be a useful tool when selective antegrade cerebral perfusion is used during aortic arch surgery, since it has been shown to detect promptly cerebral hypoperfusion mainly related to cannulas malposition,^[9,22] although larger study are required to confirm those findings.

3 Can NIRS be useful to monitor other damages? Yes.

Interestingly, NIRS studies were initially designed to investigate neurological outcomes, but turned out to show improvement in general outcomes.^[11,13] This brought new light on the debate about NIRS, since its impact might be wider than previously expected. Cerebral oxygen saturation is considered as a generic indicator of tissue viability, and brain is considered as an “index organ”: a NIRS-monitored cerebral desaturation is the alarm ring for inadequate oxygenation in other organs.^[13] However, the fact that the brain is an index organ for systemic impairment does not explain if cerebral desaturation is an early or a late sign. Some authors suggest that due to brain’s protective mechanism of flow autoregulation, other organs suffer earlier from deoxygenation and therefore cerebral desaturation is a late sign.^[23,24]

Ono, *et al.*^[25] found that cerebral desaturation was associated with acute kidney injury among patients undergoing elective CABG or valve surgery. Also, poor values of baseline cerebral oxygenation are associated with other organ failure and mortality^[26]: postoperative non-survivors had a

lower baseline cerebral saturation than survivors, and cerebral saturation less than 50% was an independent risk factor for 30 days and 1-year mortality, after adjustment for EuroSCORE and cardiopulmonary bypass duration.

Consequently, an interesting approach would be the bedside evaluation of NIRS to predict complications, especially acute renal failure, to tailor postoperative care.^[13] Would patients with severe chronic kidney disease and poor NIRS values benefit from early dialytic treatment? Would patients with severe peripheral vascular disease (at risk for acute limb ischemia) and poor NIRS values benefit from higher cardiopulmonary bypass flows or perioperative treatment with prostaglandin analogues? Would patients with poor baseline NIRS values benefit from a more liberal transfusional strategy?^[27,28]

4 Can NIRS be useful in the outpatient clinic? Maybe.

In asymptomatic patients with isolated moderate aortic stenosis, with aortic valve area greater than 1 cm² and mean transvalvular pressure gradient less than 40 mmHg, surgery is currently not recommended.^[29] Those patients are followed up in outpatient clinic with serial echocardiographic evaluations. Suddenly, they might experience a syncopal episode, and return to their cardiologist; after another echocardiographic measurement, the aortic valve stenosis is likely to be severe, and therefore they are referred for aortic valve replacement. However, the syncopal episode might have relevant complications in elderly patients, such as head trauma or hip fracture. Can a multidimensional assessment, using echocardiography and NIRS, prevent those adverse events? Declines in baseline cerebral saturation might be used as a surrogate marker of worsening of the aortic valve disease, and might trigger more frequent outpatient evaluations, which might detect a severe aortic stenosis before symptoms occurs.

5 Conclusions

NIRS to monitor cerebral oxygenation during cardiac surgery is an attractive idea, but present data do not support its use to diagnose or prevent neurological complications. Clinical studies failed to prove that interventions that restore cerebral desaturation improve neurological outcomes during coronary procedures or valvular replacement. However, in aortic arch surgery, NIRS might promptly indicate technical problems (such as malposition of the aortic cannula) and therefore its use is encouraged. As a perspective, NIRS can be used to stratify patients at risk for systemic complications (especially renal and vascular events) to tailor perioperative care, as recent studies pointed out that preoperative cerebral oxygen saturation are reflective of the severity of cardio-

pulmonary dysfunction, associated with short- and long-term mortality and morbidity. Also, an interesting approach would be the use of NIRS in the outpatient setting, to predict an incipient severity of aortic valve stenosis and prevent syncopal episodes. Future studies might investigate those unconventional uses for NIRS.

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