Near-infrared spectroscopy: What we know and what we need to know—A systematic review of the congenital heart disease literature

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Objectives: Neurologic dysfunction is a problem in patients with congenital heart disease. Near-infrared spectroscopy may provide a real-time window into cerebral oxygenation. Enthusiasm for near-infrared spectroscopy has increased hopes of reducing neurologic dysfunction. However, potential gains need to be evaluated relative to cost before routine implementation. Responding to data in ways that seem intuitively beneficial can be risky when the long-term impact is unknown. Thus, we performed a systematic review of the literature on near-infrared spectroscopy in congenital heart disease.

Methods: A literature search from 1950 to April 2007 for near-infrared spectroscopy in congenital heart disease was undertaken. We identified 54 manuscripts and\ 13 reviews.

Results: There were 47 case series, 4 randomized trials, and 3 retrospective studies. Two studies had postdischarge follow-up, one incorporating neurologic testing. Neither of these studies demonstrated a benefit. One retrospective study, which included near-infrared spectroscopy and other intraoperative measures of cerebral perfusion, demonstrated a decrease in neurologic dysfunction using this combination of monitors. Three small studies were able to correlate near-infrared spectroscopy with other clinical and radiologic findings.

Conclusions: Many centers, and even entire countries, have adopted near-infrared spectroscopy as standard of care. The available data suggest that multimodality monitoring, including near-infrared spectroscopy, may be a useful adjunct. The current literature on the use of near-infrared spectroscopy alone, however, does not demonstrate improvement in neurologic outcome. The data correlating near-infrared spectroscopy findings with indirect measures of neurologic outcome or mortality are limited. Although near-infrared spectroscopy has promise for measuring regional tissue oxygen saturation, the lack of data demonstrating improved outcomes limits the support for widespread implementation.

CHD

Supplemental material is available online.

Neurologic dysfunction is a significant problem in congenital heart disease (CHD). Historically, cardiac surgeons and cardiologists have had significant interest in acute clinical neurologic abnormalities such as stroke and seizure. With improved perioperative care, however, the prevalence of major acute neurologic abnormalities has decreased to 1% to 2% of open heart cases.[1] Of growing concern are late neurodevelopmental and behavioral problems associated with pediatric cardiac surgery.[2] These late neurologic impairments are compounded in children who require multiple operations. With increasing overall survival, the understanding of the impact of long-term neurologic sequelae on quality of life is crucial. Significant efforts from physicians and industry have been directed toward developing improved monitoring techniques for early detection of neurologic injury in hopes of averting or ameliorating subsequent complications. Current technologies include transcranial Doppler, electroencephalograms, bispectral index, biomarkers, and jugular bulb oximetry. Physician enthusiasm has increased for the use of near-infrared spectroscopy (NIRS) in the perioperative period in hopes of reducing neurologic dysfunction.

NIRS is based on the differential absorption of varying wavelengths of light by hemoglobin as it associates with oxygen. It provides a regional measurement of oxygen content in a localized tissue bed. The device can be used for both cerebral and somatic regional measurements. The value reported represents the amount of oxygen present within the tissue, including arterioles, capillaries, and venules. The measurement is venous weighted (85% venous, 15% arterial). The purported value of cerebral NIRS is the ability to obtain noninvasive, real-time information on the cerebral oxygen content in the frontal cortex that reflects both oxygen delivery and consumption. This information may help guide interventions by the surgical team or intensive care physicians to maintain theoretically safe cerebral oxygenation levels.

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Abbreviations and Acronyms
CHD = congenital heart disease
MRI = magnetic resonance imaging
NIRS = near-infrared spectroscopy
$rSco_2$ = regional cerebral oxygen saturation

NIRS technology has been described in the adult and pediatric cardiac literature in multiple clinical settings, including the intensive care unit and operating room. As with any new technology, the potential clinical gains (and limitations) need to be critically evaluated before integration into routine patient care. Each additional monitoring device comes with an additional cost and with increasing patient care complexity. In addition, responding to data in ways that seem intuitively beneficial can be risky when the long- or even intermediate-term impact on clinical outcomes is unknown. Within this context, we conducted a systematic review of the scientific literature to examine the available evidence for the use of NIRS in the care of patients with CHD.

METHODS

Eligibility Criteria

Inclusion criteria for the literature search were limited to human studies, English language, and pediatric cardiac patients; all such manuscripts using NIRS in any area of pediatric cardiology and pediatric cardiac surgery were included. Editorials, case reports, and duplicates were excluded. We reviewed narrative reviews of the use of NIRS in pediatric cardiac patients to avoid publication bias and to highlight the key difference between systematic and narrative reviews. The content of the narrative reviews was not included, as is customary, in the formal systematic review as it does not represent a primary scientific manuscript. All references were evaluated from the manuscripts to confirm inclusion of all pertinent studies.

Search Strategy

We searched the English language literature about the use of NIRS in the pediatric cardiac population from 1950 to April 2007 with MEDLINE, PreMEDLINE, EMBASE, and Cochrane databases. The MEDLINE search was performed combining the key word search: *near infrared spectroscopy, NIRS,* or *infrared spectroscopy*. This list was combined with a keyword search including the following: *pediatric cardiac surgery, CHD, pediatric, pediatric cardiology, intensive care, ICU, cardiopulmonary bypass, CPB, hypothermic circulatory arrest,* or *DHCA*. The results of the MEDLINE search are outlined in Figure 1. We identified a total of 224 manuscripts and we reviewed all abstracts. Manuscripts were excluded on adult patients, noncardiac patients, non-English language, editorials, single case reports, and duplicates. After these exclusions, a total of 48 manuscripts remained with an additional 8 manuscripts identified from the references of the narrative reviews. Further, we evaluated all articles classified as narrative review articles involving the patient population of interest along with their references to confirm an exhaustive review of the scientific literature.

Data Review and Analysis

We created a standardized data retrieval form. A single reviewer (J.C.H.) extracted data from the manuscripts and assessed clinical study site, study design, patient population, sample size, mode of monitoring, NIRS device, primary and secondary outcomes, intervention if any, and follow-up. We subclassified manuscripts into general clinical sites for review and compilation (Figure 2). It was not possible to perform a meaningful meta-analysis with generation of a summary statistic owing to variation in end points, study design, monitoring device, and statistical analyses.

RESULTS

We identified 56 manuscripts that fit the eligibility criteria (Figure 1). We also identified and reviewed an additional 13 narrative review articles for comparative purposes. For simplicity of evaluation, we sorted the manuscripts by the clinical setting (Figure 2). Of the 13 review articles, 4 narrative reviews specifically focused on NIRS in the care of patients undergoing pediatric cardiac surgery.[3-6] These review articles were not inclusive of all the potential clinical settings. The median number of manuscripts referenced within the review articles on NIRS and CHD patients was 8.5.[3-15]

The primary research manuscripts evaluated 6 different devices: INVOS (Somanetics, Troy, Mich), NIRO (Hamamatsu Photonics, Hamamatsu City, Japan), NIMS (NIMS Inc, Philadelphia, Pa), Radiometer (Copenhagen, Denmark), PSA-3N (Biomedical Science, Kanazawa, Japan), and Inspectra Tissue Spectrometer (Hutchinson Technology, Hutchinson, Minn). Owing to the natural progression of device technology, one can observe multiple models of the INVOS and NIRO devices evaluated in the literature. Various devices use different terminology to refer to cerebral oxygen content (Table 1).

Intraoperative Monitoring

A total of 38 manuscripts involved the use of NIRS in the intraoperative setting. The manuscripts were subdivided into 8 categories for summative purposes (Figure 3). Table E1 shows the author, year of publication, study design, monitoring device, patient population, number of patients, primary end point, and results. The manuscripts include 31 case series, 4 randomized trials, and 3 retrospective studies. The median sample size was 20 (range, 9–250). Two of the 38 manuscripts (in fact, the only 2 of the 56 overall manuscripts) had planned follow-up after hospital discharge; these follow-ups occurred at 3 months.[16,17] One retrospective study assessed the role of an interventional algorithm on neurologic outcomes.[18] They found that in patients with postoperative neurologic changes, more had noteworthy intraoperative cerebral perfusion changes (defined as a 50% decrease in cerebral blood flow by transcranial Doppler, excessive electroencephalographic slowing, or a decrease in regional cerebral oxygen saturation [$rSco_2$] by NIRS of > 20% for 3 minutes) that were not intervened on with a predetermined algorithm ($P = .003$).[18] Three manuscripts evaluated the association of NIRS findings with direct clinical outcomes.[19-21] One retrospective study (n = 34) demonstrated that patients who died after a single ventricle first-stage palliation had lower $rSco_2$ at the end of the operation ($P = .01$), but with no correlation to clinical neurologic abnormalities.[22] Two case