Cerebral near-infrared spectroscopy insensitively detects low cerebral venous oxygen saturations after stage 1 palliation

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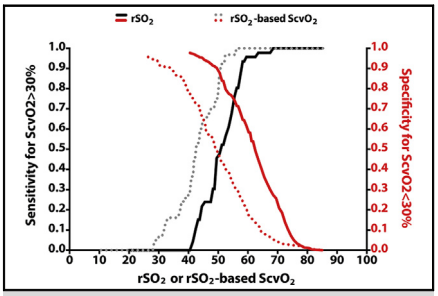
ABSTRACT

Background: Measurement of cerebral venous oxyhemoglobin saturation ($ScvO_2$) is considered a gold standard in assessing the adequacy of tissue oxygen delivery (DO_2) after the stage 1 palliation (S1P), with SvO_2 <30% often representing severely compromised DO_2. Regional oxygenation index (rSO_2) based on near-infrared resonance spectroscopy (NIRS) frequently is used to screen for compromised DO_2, although its sensitivity to detect severe abnormalities in SvO_2 is uncertain.

Methods: $ScvO_2$ was measured by co-oximetry from the internal jugular vein as clinically indicated in 73 neonates after S1P. These values were compared with cerebral rSO_2 (FORE-SIGHT; CASMED) via mixed effects model linear regression, Bland-Altman analysis, and sensitivity analysis. Because NIRS devices measure a composite of arterial and venous blood, we calculated an rSO_2-based $ScvO_2$ designed to remove arterial contamination from the rSO_2 signal: rSO_2-based $ScvO_2 = (rSO_2 - \text{arterial oxygen saturation} \times 0.3)/0.7$.

Results: Among 520 time-matched pairs of $ScvO_2$ and cerebral rSO_2, the slope of the relationship between rSO_2 and $ScvO_2$ (after we adjusted for effects of hemoglobin) was 0.37 ± 0.04 with only modest correlation ($r^2 = 0.39$), and mean bias of +8.26. When $ScvO_2$ was <30%, cerebral rSO_2 was <30 in less than 1%, <40 less than 1%, and <50 in 45.7% of data points; specificity of rSO_2 in the same range is >99%. Correction of rSO_2 for arterial contamination significantly decreased mean bias (+3.03) and improved the sensitivity of rSO_2 to detect $ScvO_2$ <30 to 6.5% for rSO_2 <30, 29% for rSO_2 <40, and 77.4% for rSO_2 <50.

Conclusions: Cerebral rSO_2 in isolation should not be used to detect low $ScvO_2$, because its sensitivity is low, although correction of rSO_2 for arterial contamination may improve sensitivity. Cerebral rSO_2 of 50 or greater should not be considered reassuring, though values below 30 are specific for low $ScvO_2$. (J Thorac Cardiovasc Surg 2017;■:1-7)



Sensitivity of near-infrared resonance spectroscopy for venous oxyhemoglobin saturation <30% is low after stage 1 palliation.

Central Message

Cerebral near-infrared resonance spectroscopy (regional oxygenation saturation [rSO_2]) insensitively detects cerebral venous oxyhemoglobin saturation less than 30% in the range of clinical interest (ie, rSO_2 30-50), a problem improved by correcting for arterial contamination (rSO_2-based cerebral venous oxyhemoglobin saturation).

Perspective

Although cerebral near-infrared resonance spectroscopy (regional oxygenation saturation) is commonly used to detect low cardiac output, the sensitivity of cerebral near-infrared resonance spectroscopy to detect venous oxyhemoglobin saturation less than 30% is low in the range of clinical interest after stage 1 palliation. This problem is ameliorated by correction of the signal for arterial contamination by back-calculating venous oxyhemoglobin saturation from regional oxygenation saturation and arterial oxygen saturation.

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Optimization of systemic oxygen delivery (DO_2) during the early postoperative period after stage 1 palliation (S1P) requires accurate assessment of venous oxyhemoglobin saturation (SvO_2). Although true mixed venous blood sampling is anatomically precluded in single-ventricle anatomy, sampling from the superior vena cava (ie, cerebral venous

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Abbreviations and Acronyms

DO_2 = systemic oxygen delivery
NIRS = near-infrared resonance spectroscopy
r^2 = correlation coefficient
rSO_2 = regional oxygenation saturation
S1P = stage 1 palliation
SaO_2 = arterial oxygen saturation
$ScvO_2$ = cerebral venous oxyhemoglobin saturation
SvO_2 = venous oxyhemoglobin saturation

Scanning this QR code will take you to a supplemental video for the article.

oxyhemoglobin saturation, $ScvO_2$) frequently is used as a representation of the adequacy of DO_2 after S1P.[1] When oxygen consumption exceeds DO_2, tissue hypoxia develops, which increases oxygen dissociation from hemoglobin and causes venous oxyhemoglobin desaturation. In the single-ventricle population, it has been suggested that $ScvO_2$ <30% represents the anaerobic threshold[2] and that maintaining $ScvO_2$ >50% in the early postoperative period is associated with improved survival.[1,3,4] Thus, accurate assessment of $ScvO_2$ after S1P is vital to the postoperative management of these patients.

Some groups have used venous oximetric catheters to permit continuous monitoring.[5] These catheters are somewhat larger in caliber than standard catheters, may be more challenging to insert, and exhibit significant drift in calibration during use, such that their use is not widespread. Thus, a mainstay of patient monitoring is the use of surface oximetry with near-infrared spectroscopy (NIRS) to measure tissue O_2 saturation. Cerebral oximetry is a noninvasive optical technology that relies on the relative transparency of biological tissues (eg, scalp and skull) to near-infrared light to measure brain oxygen saturation in an uncertain mixture of arterioles, capillaries, and venules. Commercial cerebral oximeters use continuous-wave, spatially resolved spectroscopy to measure the ratio of oxyhemoglobin to total hemoglobin, providing a cerebral hemoglobin oxygen saturation. The unit is percent (%) and is referred variably to as regional oxygen saturation (rSO_2), tissue oxygen saturation, or tissue oxygenation index, depending on the manufacturer. The ratio of venous to arterial blood in the sampled volume is approximately 70% to 30%,[6] although it can vary significantly (as much as 85%/15%).[7] Although hemoglobin is distributed unevenly within arteries, arterioles, capillaries, venules, and veins, the venous to arterial ratio is estimated and fixed during the calibration and validation of the monitor (eg, 70%-75% venous/25%-30% arterial[8-10]). Because NIRS is used commonly as a noninvasive screening tool for inadequate DO_2 after S1P, we examined the sensitivity and specificity of NIRS to detect low $ScvO_2$ in the postoperative setting.

METHODS

Patients

The following retrospective study was approved by the Institutional Review Board at Boston Children's Hospital. We retrospectively studied 84 consecutive patients undergoing single-ventricle palliation for hypoplastic left heart syndrome at our institution between January 2013 and May 2016. Cerebral rSO_2 (applied to the forehead without a preference or laterality) was measured as a part of routine clinical care during this period (FORE-SIGHT tissue oximeter; CASMED, Branford, Conn). Patients who did not have cerebral NIRS data recorded during the postoperative period (n = 3) were excluded from the study. During this period, placement of an internal jugular vein catheter with the tip in the proximal superior vena cava (at or above the junction with the right atrium) was also part of routine clinical practice. Blood sampled from the superior vena cava was analyzed routinely by co-oximetry in the hospital's core laboratory (Radiometer ABL 800; Radiometer America, Brea, Calif). Presence and position of the tip of the internal jugular catheter on the first chest radiograph after admission to the intensive care unit was assessed by 2 independent investigators (E.R. and J.K.). Data were excluded for patients in whom the tip of the catheter was deep within the right atrium (n = 8), leaving a total of 73 patients. Data also were excluded during the times that patients were on extracorporeal membrane oxygenation support. A total of 15,336 hours of patient monitoring were assessed.

Data Extraction and Processing

$ScvO_2$ and hemoglobin were extracted automatically (Boston Children's Hospital 360; MicroStrategy, Inc, Tysons Corner, Va) from the hospital database in time- and patient-stamped fashion. Similarly, rSO_2 was extracted from 1 of 2 sources. In a subset of patients (n = 20, 26.3%), the NIRS device was tethered to the bedside monitor and the data continuously (ie, every 5 seconds) stored in a database and subsequently exported (T3 Data Collection and Analytics Software System; Etiometry, Inc, Boston, Mass) and down-sampled to every 5-minute median values (MatLab, R2015b, 8.6; MathWorks Inc, Natick, Mass). In the remainder, NIRS data were entered manually by the bedside nurse at least twice per shift, and these data were extracted from the hospital database as described previously. All data were normalized to elapsed time after removal of the aortic crossclamp (the final was chosen if multiple) via a customized MatLab script.

Data Analyses

Time-matched rSO_2 measurements were compared with $ScvO_2$ measurements with the use of several techniques. First, the partial correlation coefficient and slope of the relationship were measured with mixed-effects model linear regression to account for repeated measures and to control for hemoglobin with $ScvO_2$ as the outcome. Second, the mean bias and standard deviation (limits of agreement) between the 2 measurements were compared by Bland-Altman analysis corrected for replicate measurements.[11] Third, the sensitivity and specificity of NIRS to detect $ScvO_2$ critical thresholds were assessed with receiver operating characteristic analysis by defining the presence of deficient oxygen delivery (ie, disease present) as $ScvO_2$ <30%, <40%, or <50%. Sensitivity and specificity curves were then created to describe the rSO_2 values at which NIRS is sufficiently sensitive to detect $ScvO_2$ <30%.