Correlation between Regional Cerebral Saturation and Invasive Cardiac Index Monitoring after Heart Transplantation Surgery

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Abstract

Keywords

- cerebral near infrared spectroscopy
- regional oxygen saturation
- mixed venous saturation
- cardiac output
- cardiac index
- heart transplant
- pediatric

The present study assessed the correlations between cerebral regional saturation detected by near infrared spectroscopy (NIRS) and cardiac index (CI) measured by pulmonary artery catheter. This was a retrospective cohort study conducted in the cardiac intensive care unit in a tertiary care children's hospital. Patients younger than 18 years of age who underwent heart transplantation and had a pulmonary artery catheter on admission to the pediatric cardiac intensive care unit between January, 2010, and August, 2013, were included. There were no interventions. A total of 10 patients were included with median age of 14 years (range, 7–17). Indications for transplantation were dilated cardiomyopathy ($n = 9$) and restrictive cardiomyopathy ($n = 1$). Mixed venous oxygen saturation (SvO_2), cerebral regional tissue saturation (rSO_2), and CI were recorded hourly for 8 to 92 hours post-transplantation. Spearman's rank correlation coefficient was used to assess correlations between SvO_2 and cerebral rSO_2 and between CI and cerebral rSO_2 . A total of 410 data points were collected. Median, 25th and 75th percentiles of cerebral rSO_2 , CI, and SvO_2 were 65% (54–69), 2.9 L/min/m² (2.2–4.0), and 75% (69–79), respectively. The correlation coefficient between cerebral rSO_2 and CI was 0.104 ($p = 0.034$) and that for cerebral rSO_2 and SvO_2 was 0.11 ($p = 0.029$). The correlations between cerebral rSO_2 and CI and between cerebral rSO_2 and SvO_2 were weak. Cerebral rSO_2 as detected by NIRS may not be an accurate indicator of CI in critically ill patients.

Introduction

Cardiopulmonary monitoring is crucial to the successful management of critically ill patients.^{1,2} Traditionally, invasive monitoring has been used to assess cardiac output (CO),

but these approaches pose potential risks for vascular injury, infection, and thrombosis.^{3–5} Therefore, indirect assessments of CO become paramount in the care of the critically ill patient. Mixed venous oxygen saturation (SvO_2) has been used as a surrogate marker of CO.⁶ It is considered the gold

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standard for the assessment of oxygen delivery and extraction at the tissue level.⁷ Tissue oxygen delivery depends on CO, hemoglobin, and arterial oxygen saturation; therefore, in a state of stable hemoglobin, oxygen saturation, and oxygen extraction, low SvO₂ may indirectly reflect low CO state.^{7,8}

Near infrared spectroscopy (NIRS) is a technology that utilizes infrared light to continuously monitor regional tissue saturation (rSO₂).^{9,10} Regional tissue saturation is measured via cutaneous sensors placed on various parts of the body corresponding to a specific vascular bed. The sensors measure light absorption of oxygenated and deoxygenated hemoglobin in the underlying vascular beds.^{11,12} Blood in the vascular bed consists of 75 to 80% venous blood. While this ratio can vary in critically ill patients, NIRS light absorption primarily reflects venous saturation.^{12,13} Cerebral rSO₂ obtained by NIRS has been shown to correlate with trends in SvO₂ measured on invasively obtained blood samples from the superior vena cava.^{14–16} Although recent reports have shown that using rSO₂-guided interventions might affect clinical outcomes^{17,18}, the ability of NIRS to predict the absolute measure of SvO₂, jugular bulb oxygen saturations, and cardiac index (CI) remains controversial.^{19–21}

To our knowledge, this study is the first to determine the correlation between cerebral rSO₂ and CI measured by continuous pulmonary artery (PA) catheter in critically ill pediatric patients.

Methods

Study Cohort

The Institutional Review Board at Duke University Health System approved the study protocol with waiver of informed consent. The charts of consecutive pediatric patients, who underwent heart transplantation between January 2010 and August 2013, were retrospectively reviewed. All patients who had a PA catheter in place at the time of admission post-transplant were included in the study. Patients without PA catheters were excluded as were those who underwent heart transplantation for end-stage heart failure resulting from congenital heart disease due to concern for the increased risk of large aortopulmonary collateral burden or presence of pulmonary arteriovenous malformations. Cerebral rSO₂ was monitored using two NIRS sensors placed on the patient's right and left sides of forehead (Cerebral OxyAlertTM, Somanetics InvoS 5100C, Somanetics Corporation, Troy, Michigan, United States) in all patients per the pediatric cardiac intensive care unit (PCICU) standard of care. PA catheters (Swan-Ganz CCombo, Edwards Lifesciences LLC, Irvine, California, United States) were placed intraoperatively, and position was confirmed by chest radiograph on PCICU admission and waveforms. Two NIRS sensors were placed on the forehead on arrival to the PCICU. Patient vital signs, NIRS, and PA catheter data were monitored hourly immediately after ICU admission as per PCICU protocol. Data obtained by the PA catheter included right atrial pressure, PA pressures (systolic, diastolic, and mean), SvO₂, and CI measured by flow and thermodilution (TD). Invasive blood pressures were monitored via peripheral arterial line.

Measurements

Cardiac index (L/min/m²) and SvO₂ (%) were obtained using PA catheter, and cerebral rSO₂ (%) was recorded hourly for 8 to 92 hours post-transplantation. SvO₂ was calibrated every shift against blood oxygen saturation measured by co-oximetry as per our PCICU standard of care. Catheter position was confirmed by waveform; PA waveform was used to confirm distal tip of catheter and atrial waveform for proximal port. Catheter placement was confirmed prior to each CO assessment by TD. CO was measured hourly via the PA catheter using TD method. Three measurements were obtained with normal CO curves that were within 10% of the median value and average of the three measurements was computed as our CO. All measurements were obtained with the patient in the same supine position. A limitation of the TD method of obtaining CO is that we occasionally needed to inject multiple times to obtain a normal CO curve. SvO₂ was measured at the tip of the PA catheter in the PA. Heart rate (bpm), blood pressure (mm Hg), pulse oximetry (%), and core temperature (°F) were also recorded hourly.

Statistical Analysis

We used standard summary statistics including medians with 25th, and 75th percentiles, and counts and percentages to describe continuous and categorical study variables. The distribution of study variables across groups was compared using Wilcoxon rank sum, chi-square, and Fisher's exact tests as indicated. We evaluated the correlation between noninvasive hemodynamic parameters and CI using Spearman's rank correlation coefficients. All analyses were conducted using Stata 13.1 (College Station, Texas, United States), and we considered $p < 0.05$ statistically significant.

Results

Twenty-four patients underwent heart transplantation between January 2010 and August 2013. Ten patients were included in the study. Sixty percent were males, median age was 14 years (range, 7–17), and median weight was 64.5 kg (range, 31–76). Pre-transplant diagnoses were dilated cardiomyopathy ($n = 9$) and restrictive cardiomyopathy ($n = 1$; ▶Table 1). The median (25th, 75th percentile) mechanical ventilation times were 24 hours (8,58). The median use of inhaled nitric oxide was 4.5 hours (1,18).

Table 1 Demographic and variables for the study cohort

Variable	Patients (n = 10)
Age at transplant, ^a years	14 (12,16)
Male	6 (60%)
Weight at transplant, ^a kg	64.5 (53.0,76.5)
Diagnosis	
Dilated cardiomyopathy	9 (90%)
Hypertrophic cardiomyopathy	1 (10%)

^aMedian (25th, 75th percentiles).

No complications were reported in association with the use of cerebral NIRS sensors.

A total of 410 paired samples of each cerebral rSO_2 -CI and cerebral rSO_2 - SvO_2 were collected at 1-hour intervals. Paired samples were collected for a period of 8 to 96 hours post-operatively. The median (25th, 75th percentile) number of paired samples per patient was 28 (19.3, 55.3).

The median CI was 2.9 L/min/m² (2.2, 4). The median cerebral rSO_2 and SvO_2 were 65% (54, 69) and 75% (69, 79), respectively (►Table 2). The correlation coefficient between cerebral rSO_2 and CI was weak ($r = 0.104$, $p = 0.034$) (►Fig. 1). Similarly, the correlation coefficient between cerebral rSO_2 and SvO_2 was weak ($r = 0.11$, $p = 0.029$; ►Fig. 2). Finally, cerebral rSO_2 and CI trends over time were concordant at times (►Fig. 3).

Discussion

Low cardiac output syndrome (LCOS) is a common post-operative complication after surgery for heart transplantation.^{17,22} It is associated with prolonged intubation, ICU

Table 2 Hemodynamic parameters (median, 25th, 75th percentiles) for the study cohort

Parameter	Patients (n = 10)
HR (bpm)	109 (99,110)
MAP (mm Hg)	75 (70,80)
SvO_2 (%)	75 (69,79)
Cerebral rSO_2 (%)	65 (54,69)
CO (L/min)	5.6 (3.9,6.7)
CI (L/min/m ²)	2.9 (2.2,4.0)

Abbreviations: CO, cardiac output; CI, cardiac index; HR, hazard ratio; MAP, mean arterial pressure; SvO_2 , mixed venous oxygen saturation; rSO_2 , cerebral regional tissue saturation.

Fig. 1 Correlation between cardiac index and cerebral regional tissue saturation (rSO_2). The 95% confidence intervals of the linear regression fit are shown in gray.

Fig. 2 Correlation between mixed venous saturation and cerebral regional tissue saturation (rSO_2). The 95% confidence intervals of the linear regression fit are shown in gray.

length of stay, hospital length of stay, and increased cost.²³ LCOS is also associated with increased risk of cardiac arrest, organ dysfunction, need for ECMO, and death.²³ In the current era, a practical approach to the assessment of CO in the critically ill patient depends on clinical parameters, such as arterial blood pressure, heart rate, peripheral perfusion, urine output, and core-toe temperature gradient.²⁴ This mode of assessment is flawed with the lack of objectivity and prone to errors that could lead to inaccurate clinical judgment. The ideal monitoring system is one that is noninvasive, capable of predicting imminent low CO state before it actually occurs, and able to reflect the impact of clinical interventions in real time.

NIRS offers a continuous, noninvasive, real-time monitor of rSO_2 in critically ill patients. Recently, cerebral rSO_2 has been used as an indirect measure of SvO_2 and a surrogate measure of CO.²⁵ Although rSO_2 accuracy can be affected by multiple factors such as hyperbilirubinemia, excess melanin, scalp tissue, or edema, and do not necessarily indicate

Fig. 3 Trend in cardiac index (CI) (red) and cerebral regional tissue saturation (rSO_2) (blue) overtime.

changes in CO,²⁶ direct correlation between cerebral rSO₂ and CI has not been well-established.²⁰ In this study, we demonstrate a weak correlation between rSO₂ and CI in our patient population. In contrast to our results, Bhutta et al²⁷ reported a significant correlation between rSO₂ measured by cerebral NIRS and CI (measured with PA catheter) in pediatric transplant patients during routine annual myocardial biopsy in the cardiac catheterization laboratory. Although their patient population appeared similar to ours, they were not critically ill. Our patients were studied in the immediate postoperative period where other factors can affect regional blood circulation, including the use of inotropes and vasopressors. In their study, CI was a one-time measurement, whereas in our patient population, multiple data points were obtained on each patient.

We also observed a poor correlation between cerebral rSO₂ and SvO₂. Our result is consistent with the findings of Moreno et al²⁰ who reported that cerebral and kidney rSO₂ did not correlate with SvO₂ measured in neonates after open-heart surgery. Similarly, Rescoe et al¹³ found that cerebral rSO₂ in isolation might not detect low cerebral venous oxyhemoglobin saturation in neonates after stage one palliation surgery. They also noted that providers should not consider high cerebral rSO₂ as reassuring tool without considering other markers of appropriate oxygen delivery.

In contrast, Marimón et al²¹ found a good correlation between the absolute values of rSO₂ and SvO₂ in pediatric patients after cardiac surgery; however, in this study, SvO₂ was obtained in the superior vena cava and not in the PA. Similarly, Paarmann et al²⁸ reported a close correlation between SvO₂ and cerebral rSO₂ in adults undergoing transapical transcatheter aortic valve implantation. They also noted that rSO₂ was lower than the SvO₂ and concluded that rSO₂ underestimated SvO₂ in their patient population. Such a statement may not be generalizable as in a subgroup of our patients; rSO₂ was slightly higher than SvO₂.

Finally, though our study demonstrated a weak correlation between cerebral rSO₂ and SvO₂ values, our results indicated that NIRS and SvO₂ followed similar trends at times. Other researchers have showed such trends as well.^{14,16,29} Due to the variability in trends at times and no statistical significance, conclusions could not be made regarding the ability of cerebral rSO₂ prediction of low CO state or SvO₂. To our knowledge, our study is the first to report the relationship between cerebral NIRS and CI invasively measured by continuous PA catheter among critically ill pediatric patients.

Limitations

A limitation of this study is its retrospective design and small sample size. Moreover, our sample was limited to patients 7 to 17 years old as PA catheters were not placed or used in younger heart transplant patients during the study period. Also, although the patients were continuously monitored, the recorded data only capture hourly data points and, therefore, does not capture variabilities that may have occurred. In addition, most of patients in our study were hemodynamically stable with narrow SvO₂ and CI values.

Finally, our study did not assess the correlation between multisite rSO₂ and CI. Multisite rSO₂ reflects regional oxygenation in two opposite poles of circulation, cerebral and somatic, and the compensatory response to low CO can be reflected in a decrease in somatic rSO₂ while cerebral rSO₂ is preserved.⁹

Conclusions

This study, which captured multiple data points per patient, demonstrated weak correlation between cerebral NIRS and SvO₂. In addition, there was a poor correlation between cerebral NIRS and CI. We conclude that rSO₂ obtained by cerebral NIRS measurement does not replace invasive CO and SvO₂ monitoring in critically ill children. However, cerebral NIRS trends may still provide useful clinical information in the management of pediatric cardiac patients. Continuous cerebral NIRS monitoring alone and not combined with clinical assessment may not be helpful in the evaluation of changes in CI and clinical status of critically ill pediatric patients. Further studies are required to explore the use of cerebral NIRS as a tool for early detection, or prediction, of hemodynamic compromise among critically ill pediatric patients.

Note

This study was conducted at Duke Children's Hospital, Durham, NC.

Conflict of Interest

Dr. Cheifetz received funding from Philips (advisor) and UpToDate (contributing author).

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The remaining authors have disclosed that they do not have any potential conflicts of interest.

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