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Monitoring abdominal near-infrared spectroscopy during feeds in neonates with CHD recovering from surgery: a feasibility study

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Abstract

Objective: Monitoring cerebral and renal near-infrared spectroscopy for regional venous oxygenation is a common practice in the postoperative care of neonates recovering from surgery for CHD. In this study, we aimed to test the feasibility of using this technology for monitoring changes in splanchnic perfusion during feeds in infants recovering from cardiac surgery. *Methods:* We monitored renal and splanchnic near-infrared spectroscopy in 29 neonates once recovered from the critical postoperative state and tolerating full enteral nutrition. Infants were tested over 3 feeds for splanchnic regional oxygenation (rO_2), arterial to splanchnic saturation difference and splanchnic to renal regional oxygenation ratio. *Result:* Splanchnic regional oxygenation data were obtained with no failure or interruptions. Interclass correlation for agreement between measurements suggested good repeatability: 0.84 at baseline and 0.82 at end of feed. Infants with physiologic repair ($n = 19$) showed a trend towards increased splanchnic regional oxygenation at the end of feeds and were more likely to achieve regional oxygenation > 50% compared to infants with shunt-dependent circulation ($n = 10$, $p = 0.02$). Calculating AVO_2 and regional oxygenation index did not result in improved test sensitivity. *Conclusion:* Monitoring splanchnic regional oxygenation during feeds for infants recovering from congenital heart surgery is feasible and reliable. These results suggest that near-infrared spectroscopy could be further studied as a tool for bedside monitoring to assist in feeding management and prevention of necrotising enterocolitis in this sensitive patient population.

Introduction

Neonates with complex CHD who are recovering from surgical intervention have poor intake and high energy requirement and are frequently malnourished. Adequate nutrition is essential for growth, wound healing, and immune function.[1] Meeting the nutritional needs is often challenged by fluid limitation and risk of gut hypoperfusion secondary to low cardiac output, hypoxaemia, poor vasoreactivity, or ductal-dependent change in aortic flow.[2] The clinical assessment of the infant's hemodynamic status is crucial in deciding whether to advance enteral nutrition, a priority for the care team.[1] Enteral nutrition avoids the complications of prolonged use of parenteral nutrition and supports physiologic and healthy development of the neonate. Liberal advancement of enteral feeds, however, has to be balanced with the risk of feeding intolerance and intestinal complications after cardiopulmonary bypass.[3–5] Necrotising enterocolitis continues to compromise outcomes of neonatal cardiac surgeries despite many advancements in perioperative care. Necrotising enterocolitis affects about 6–7% of infants with CHD and up to 13% among neonates palliated with a systemic-to-pulmonary shunt.[6] Among these infants with single-ventricle palliation, necrotizing enterocoolitis tends to be a postoperative complication in up to 88% of cases and is associated with introduction or reintroduction of feeds.[7] Necrotising enterocolitis is a serious complication of neonatal congenital heart surgery and is associated with high morbidity and mortality.[8–10] This complication, as well as malabsorption, poor acquisition of feeding skills, and feeding tube dependence, continues to complicate postoperative recovery and prolong hospital stay.[11,12] The implementation of postoperative feeding advancement protocols has been shown to improve nutritional and safety outcomes, but diagnostics to guide these protocols are lacking.[13,14]

The aetiology of feeding intolerance and necrotising enterocolitis in neonates is a topic of debate and is particularly less studied in the CHD population. Necrotising enterocolitis of prematurity is associated with bacterial translocation in the intestinal wall and a septic inflammatory response. In term infants, in contrast, it is almost universally associated with CHD

and shows different characteristics that are indicative of splanchnic hypoperfusion as the central pathophysiology. Enterocolitis in CHD can present earlier and is characterised by lower inflammatory markers, involvement of watershed areas of the intestine, and a higher risk for perforation.[15] Doppler-based studies suggest an association between compromised flow patterns in the aorta or superior mesenteric artery and the risk for necrotising enterocolitis, both in premature [16] and CHD infants.[17–19] These findings suggest that intestinal complications occur when the circulation is unable to support the changing demands of the alimentary system during feeds.

Near-infrared spectroscopy is an innovative diagnostic tool that provides a continuous and non-invasive alternative to sampling venous or pulmonary arterial blood for measuring oxygen content too estimate tissue perfusion and cardiac output. Using a thin skin probe connected to a dedicated monitor, infrared spectroscopy analyses non-pulsatile blood for oxygen saturation, providing an ongoing evaluation of aortic to venous saturation difference, a surrogate marker of cardiac output.[20] The clinical implications of its use for specific organs are now studied and expanded. In this study, we aimed to test the feasibility of monitoring splanchnic regional oxygenation using near-infrared spectroscopy during feeds in infants recovering from congenital heart surgery. The goal of this feasibility study is to propose a non-invasive tool that may assist the clinician in identifying infants who are at high and low risk for necrotising enterocolitis and to individualise postoperative feeding advancement accordingly.

Subjects and methods

A single-centre prospective study was performed, evaluating newborn infants who were admitted for cardiac surgery at Seattle Children's Hospital from 11/2021 to 5/2023. This study was approved by the Institutional Review Board. Legal guardians were approached for consent while the infant was admitted to the cardiac ICU in the perioperative period and before transferring to the acute care floor. Eligibility criteria included all infants younger than 2 months of age at the time of testing who underwent open heart surgery, defined as surgery that required circulatory support on cardiopulmonary bypass. Exclusion criteria included infants who had cardiac surgery that did not require bypass support, infants born prematurely before 35 weeks' gestation, infants with history of preoperative enterocolitis or with congenital gastrointestinal malformation and infants with major brain anomaly or chromosomal abnormality. Infants were also excluded if remained on continuous feeds or feeds provided over 90 minutes or more throughout admission or infants with prior concern for skin reaction to adhesives or the infrared spectroscopy probes.

Testing and data collection

Infants were tested within 72 hours of transfer to the acute care floor. The skin was cleaned and dried and INVOS^{TM} Cerebral/Somatic Oximetry Infant-Neonatal Sensors (Medtronic, MN, USA) were placed, one in splanchnic position (horizontally, placed 0.5 cm under the umbilicus), and one on the right or left flank in standard somatic / renal position. Monitoring was performed for over 3 feeds within 24 hours and the monitor was disconnected between feeds. Through the 3 tested feeds, no changes in delivery mode or content were made. Splanchnic regional oxygenation, renal regional oxygenation, and arterial saturation from standard pulse-oximeter, were recorded at the start of feeds, midway (25–50%) and finish, if feeds given over 45 minutes or more. At each time point, the average of 5 consecutive reads was recorded for each value. For oral or shorter bolus feeds, time points were adjusted to start, 15–30 minutes and 60 minutes. For infants who took a timed attempt at oral feed and then continued to tube feed, an additional time point at the end of oral attempt was taken; this additional time point was scarce and showed no significant difference from other midway measurements and is thus not reported in the analyses below. For 2 infants, only two feeding events were monitored for patient-related reasons or parental preference. For 2 infants with high variability in the recorded values, a fourth feeding event was recorded. Failure to obtain near-infrared spectroscopy data was defined as no read or regional oxygenation< 15% (that is below the sensitivity threshold of the device per manufacturer). Patients' demographic and clinical data were reviewed and recorded from the electronic medical record. For the day of testing, updated feeding mode (oral vs. nasogastric tube), type (formula or breastmilk-based nutrition) and caloric concentration of feeds were recorded, as well as duration or feeds and most recent haematocrit.

Data analysis

Patient demographics were summarised by calculating means and standard deviation for continuous covariates and proportions (percent) for categorical variables. Clinical covariates are shown by high-risk and low-risk groups, and mean differences are tested statistically using *t*-tests. For this risk analysis, 'high-risk' were infants who had undergone palliation with a systemic-to-pulmonary shunt, post-operatively with a 'single-ventricle physiology', and 'low-risk' were infants who undergone a biventricular repair with expected normal arterial saturations.

Data were analysed for the average of 3 feeds for three splanchnic near-infrared spectroscopy outcome measures:

1. Splanchnic regional oxygenation
2. Standard pulse-oximeter to splanchnic regional oxygenation difference (aorto-venous oxygen difference, AVO_2). This measure was aimed to assess tissue oxygen extraction while correcting for hypoxemic state in cyanotic CHD.
3. Splanchnic to renal regional oxygenation ratio, aimed to test whether changes in regional flows in the splanchnic circulation may be amplified or better identified if reviewed in relation to counter changes in the abdominal aorta.

To assess intraclass correlation, two-way random effect intraclass correlation measures for agreement using the average of 3 measurements were used. Time trends were assessed using pairwise *t*-tests between start and end of feedings. Outcome measure distributions were plotted graphically over the feeding times with median and 5th, 25th, 75^{th,} and 95th interquartile lines presented. Splanchnic regional oxygenation was dichotomised using a clinically meaningful threshold of 50%, and Fisher's exact test was used to compare between start and end of feeding. *P*-values less than 0.05 are considered significant.

Results

This feasibility study tested 29 newborn infants within 72 hours of transfer from the cardiac ICU to the acute care floor during their hospitalisation after cardiac surgery. Demographic information is summarised in Table 1. Of this cohort, 10 infants (34%) were

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Table 1. Demographics

	All infants ($n = 29$)
Gender	Female, 13 (45%)
Race / ethnicity	Caucasian, 17 (59%) Asian / Pacific Islander, 4 (14%), Asian / Caucasian, 1 (4%) Black, 3 (10%), Black / Caucasian, 1 (4%) Hispanic 2 (8%), Family preferred not to answer, 1
Gestational age (SD)	39 + 2 weeks (± 9 days)
Birthweight Average (SD) SGA, *n* (%)	 3.3 kg (± 0.6) 10 (34%)

SD: standard deviation; SGA: small for gestational age.

considered *high-risk* for necrotising enterocolitis (9 with single-ventricle lesion, one with pulmonary atresia and discontinuous branch pulmonary arteries who eventually underwent a biventricular repair later in infancy). The clinical characteristics of both groups are described in Table 2. Overall, infants had their cardiac surgery at an average (± standard deviation) of 6.2 (± 6.9) days of life and testing was performed 13.8 (± 8.7) days after surgery. It is notable that infants in the high-risk group were tested significantly later after their surgery, 20.4 (± 10.7) vs 10.3 (± 4.9) days. Also, the high-risk group tended to have a higher haematocrit, 36.5% (± 4.3) vs 30.1% (± 3.9), and received feeds of higher caloric concentration, 24.8 (± 2.4) vs 22.7 (± 2.36) kcal/oz. In follow-up until hospital discharge, feeding intolerance (recurrent emesis that required change in feeding plan) occurred in two of the high-risk and one of the low-risk infants. Necrotising enterocolitis (Bell II classification) was diagnosed in one infant of the high-risk group with the incidental radiographic finding of pneumatosis and was medically treated with one week of holding enteral feeds and intravenous antibiotics.

Overall, infants were tested 2–4 times each with a total of 87 feeding events tested. Splanchnic spectroscopy data was obtained with no failure or interruptions. The repeatability of regional oxygenation capture was evaluated by calculating interclass correlation for agreement between 3 measurements as summarised in Table 3. Interclass correlation score suggested good repeatability at baseline (0.84 [confidence interval 0.71, 0.92]) and finish (0.82 [0.65, 0.91]) for splanchnic regional oxygenation, similar to the agreement for renal regional oxygenation (0.78 [0.59, 0.89] and 0.86 [0.73, 0.93], respectively). Near-perfect correlation for agreement for arterial pulse-oximetry measurements served as reference control (0.96 [0.93, 0.98] and 0.97 [0.94, 0.99], respectively). The correlation score was lower when evaluating for a single measurement agreement (0.64 [0.45, 0.8] at baseline and 0.6 [0.38, 0.77] at finish for splanchnic regional oxygenation).

Reviewing regional oxygenation changes through feeds for the entire cohort, no significant changes were seen when comparing the average values of splanchnic near-infrared spectroscopy outcome measures from start to midway or end of feed. Splanchnic regional oxygenation increased from 52% ± 13.9 at baseline, to 52.6% ± 9.5 midway and 53% ± 10.5 at the end of feed. Splanchnic AVO_2 reduced from 42.7% ± 13.6 to 41.8% ± 9.2 and 41.2% ± 10.2, respectively. Splanchnic to renal regional oxygenation ratio increased from 0.8 ± 0.2 at start and midway through feed to 0.9 ± 0.2 at the end of feed. When looking at the average change by risk group, no significant changes in the average splanchnic regional oxygenation, AVO_2 or regional oxygenation ratio were noted for the high- or low-risk groups. Figure 1 plots the distribution of all three measures by risk group. Qualitatively, lower variability in splanchnic regional oxygenation distribution at the end of feed compared to baseline measurements was noted in the low-risk group and more infants in this group reached higher regional oxygenation. By the end of feed, 15 of 19 patients in the low-risk group reached regional oxygenation > 50% vs 3 of 10 in the high-risk group ($p = 0.017$, compared to 12 of 19 and 4 of 10 patients at the start of feed, respectively, $p = 0.27$). Univariate analysis tests for the effect of all other recorded variables that are detailed in Table 2 on change in splanchnic spectroscopy measures were performed, yielding no significant results (data is not shown).

Discussion

In this pilot study we report the feasibility of monitoring regional splanchnic oxygenation during feeding for infants recovering from congenital heart surgery. We observed no testing failures and good repeatability in a cohort of 29 patients and 87 testing events. Feasibility is perhaps further supported by regional oxygenation trends that were consistent with our hypothesis when comparing infants at high-risk and low-risk for intestinal hypoperfusion. This study was not powered to define physiologic changes or set the expected range of values for splanchnic regional oxygenation, and therefore, the clinical potential of near-infrared spectroscopy for bedside monitoring of gut perfusion and its possible implication for postoperative feeding management requires larger prospective studies.

The preliminary measure to validate monitoring regional oxygenation during feeds in the sub-umbilical position was repeatability of testing. Repeatability was assessed by scoring the agreement between regional oxygenation measurements at each of the pre-defined time points over 3 feeds for each infant. For this cohort, size interclass correlation scores for agreement of 0.5–0.75 indicate moderate repeatability and 0.75–0.9 good repeatability. Scores of 0.9 and above are excellent and expected when measuring values with no expected physiologic variability.[21] Overall, we observed good repeatability for splanchnic regional oxygenation that is similar to renal regional oxygenation. As expected, Standard pulse-oximeter repeatability was excellent, and qualitatively, the regional oxygenation correlation scores were lower when Standard pulse-oximeter scores were on the lower end, midway through feeds (suggesting greater individual variability at that time). We hypothesise that good agreement between measurements per individual indicates that regional oxygenation measures reliably reflect inherent circulatory state that may overcome changing physiologic factors (i.e. infant's activity, administration time of vasoactive medications, diurnal or temperature variations etc). Finally, in this study, the baseline average regional oxygenation of 52% ± 13.9) is to the baseline average reported in prior studies that tested abdominal probe position.[22–24]

Near-infrared spectroscopy detects oxygenated and deoxygenated haemoglobin in non-pulsatile blood within a window of about 1 cm^3, 2–3 cm beneath the sensor. The captured blood volume is predominantly venous (around 75%) and thus closely reflects post-capillary saturations.[20] Each body organ has a different extraction rate and changing demands, therefore, regional oxygenation is not an exact equivalent to mixed venous saturation. Still, early studies showed good correlation between cerebral regional oxygenation and jugular vein saturations as well as renal regional oxygenation

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Table 2. Clinical data, high-risk and low-risk groups

	Low-risk Physiologic repair ($n = 19$)	High-risk Single Ventricle physiology ($n = 10$)	
Cardiac Diagnosis: variant	D-TGA 6 (20.7%): with VSD 3 VSD 5 (17.2%): CoA 2, HAA 1, IAA 1, MS 1 HAA 3 (10.3%): IAA 1, Shone complex 1 Truncus arteriosus 3 (10.3%): Type II 2, Type IV 1 TAPVR 1 (3.4%) ToF / pulmonary atresia 1 (3.4%)	HLHS 5 (17.2%): MA/AA 4, MS/AS 1 Unbalanced AVSD 2 (6.9%): HAA 1, pulmonary atresia 1 DORV, HAA 1 (3.4%) DILV, D-TGA, IAA 1 (3.4%) Tricuspid atresia, D-TGA 1 (3.4%)	–
Birthweight	3.4 kg (± 0.6)	3.1 kg (± 0.6)	$p = 0.3$
Gestational Age	39 + 2 weeks (± 9.9 days)	39 weeks (± 7.6 days)	$p = 0.62$
Surgery			
Cardiac Surgery: major modification	Arterial switch 7 (24.1%): VSD closure 3, arch repair 1 Aortic arch repair 6 (20.7%): VSD closure 4 Truncus arteriosus repair 3 (10.3%) TAPVR repair 1 (3.4%) TOF repair 1 (3.4%): transannular patch VSD closure 1 (3.4%): resection of supra-mitral ring	Norwood, Sano shunt 6 (20.7%): partial ASD closure 1 Arch repair, pulmonary artery band 3 (10.3%) Pulmonary artery unifocalisation 1 (3.4%): VSD left open	–
Arch intervention	9 (47%)	8 (80%)	$p = 0.13$
Age at surgery	7.2 days (± 8.4)	4.5 days (± 1.2)	$p = 0.3$
Delayed sternal closure Days post-op	8 (42%) Range: 1–3 days	7 (30%) Range: 1–7 days	$p = 0.25$
Post-op ECLS	0	1 (10%)	–
Cardiopulmonary Bypass time	202.4 min (± 67.6)	171.3 min (± 45.4)	$p = 0.2$
Hypothermic arrest	4 (21%)	5 (50%)	$p = 0.2$
Outcomes			
Post-op time on inotropic support	3.9 days (± 2.3)	5.8 days (± 4.0)	$p = 0.12$
Post-op time to extubation	3.7 days (± 1.8)	5.0 days (± 3.3)	$p = 0.2$
Kidney injury during admission	4 (21%) post-op, 1 (5.2%) pre-op	3 (30%) post-op	$p = 1$
Hemoccult positive during admission	2 (10.5%)	6 (60%)	$\mathbf{p = 0.001}$
Post-op time to initiate feeds	3.1 days (± 1.7)	6.3 days (± 3.7)	$\mathbf{p = 0.003}$
Post-op time to reaching enteral feeds at caloric goal	11.7 days (± 4.6)	22.9 days (± 10)	$\mathbf{p < 0.001}$
Length of stay	14.1 days (± 5.2)	26.0 days (± 10.6)	$\mathbf{p < 0.001}$
Moderate or severe systemic AVVR	2 (10.5%)	2 (20%)	$p = 0.59$
Moderate or severe aortic insufficiency	2 (10.5%)	0	–
Testing day data			
Age at testing	17.4 days (± 11.2)	24.9 days (± 10.5)	$p = 0.09$
Post-op time to testing	10.3 days (± 4.9)	20.4 days (± 10.7)	$\mathbf{p = 0.001}$
Haematocrit	30.1% (± 3.9)	36.5% (± 4.3)	$\mathbf{p < 0.001}$
Feeding mode	NGT 10 (52.6%) NGT + oral 5(26.3%) All oral 4 (21.1%)	NGT 4 (40%) NGT + oral 5(50%) All oral 1 (10%)	–
Formula (vs. breastmilk ± additive)	2 (10.%)	2 (20%)	–
Caloric concentration	22.7 kcal/oz (± 2.36)	24.8 kcal/oz (± 2.4)	$\mathbf{p = 0.049}$

Demographic and clinical characteristics of the low- and high-risk groups are presented: number (percentage) for dichotomic values, average (standard deviation) for nominal values. D-TGA: D-transposition of the great arteries; VSD: ventricular septal defect; CoA: coarctation of the aorta; HAA: hypoplastic aortic arch; IAA: interrupted aortic arch; MS: mitral stenosis; TAPVR: total anomalous pulmonary venous return; TOF: tetralogy of Fallot; HLHS: hypoplastic left heart syndrome; AVSD: atrioventricular septal defect; DORV: double-outlet right ventricle; DILV: double inlet left ventricle; ASD: atrial septal defect; ECLS: extracorporeal life support; AVVR: atrioventricular valve regurgitation; NGT: nasogastric tube.

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Table 3. Interclass correlation score for average across three feeds

Interclass correlation score (95%CI)	Renal rO_2	Splanchnic rO_2	Arterial SpO_2
Baseline	0.78 (0.59, 0.89)	**0.84** (0.71, 0.92)	0.96 (0.93, 0.98)
Midway	0.69 (0.4, 0.85)	0.7 (0.41, 0.86)	0.91 (0.82, 0.96)
End of feed	0.86 (0.73, 0.93)	**0.82** (0.65, 0.91)	0.97 (0.94, 0.99)

Interclass correlation score for average across 3 feeds is presented (with 95th percentile confidence interval), analysed for 27 patients who had at least 3 testing events done.
CI: confidence interval; rO_2: regional oxygenation; SpO_2: systemic pulse-wave oxygenation.

and inferior vena cava saturation, a correlation that is especially high in infants.[25–27] Regional oxygenation data can thus provide a continuous indication to organ oxygen reserve, and when calculating AVO2, oxygen extraction, both complementing markers of organ perfusion. Low cerebral regional oxygenation measurements were associated with cerebral injury during cardiac surgeries in paediatric and adults.[28] In the paediatric cardiac ICUs, the use of a dual near-infrared spectroscopy system, renal (somatic) and cerebral, has become standard of care in most institutions and have shown to capture low cardiac output state and improve postoperative outcomes.[26,28] Raymond et al. studied the benefit of adding renal to cerebral regional oxygenation ratio of > 0.75 as a marker of adequate systemic perfusion and criteria for allowing rate increase in a newly implemented postoperative feeding protocol in infants with single-ventricle heart disease.[14] The authors demonstrated a lower rate of necrotising enterocolitis when the protocol included infrared spectroscopy monitoring. In this pilot study, we suggest targeting gut perfusion specifically to enhance the diagnostic accuracy of infrared spectroscopy for the same purpose.

Few studies evaluated the potential use of near-infrared spectroscopy to estimate splanchnic venous oxygenation.[29] Abdominal spectroscopy readings in infants were previously correlated with Doppler flows in the superior mesenteric artery, validating that it reads mesenteric regional oxygenation. Studies then correlated low abdominal regional oxygenation during feeds with the development of feeding intolerance and necrotising enterocolitis in premature infants and CHD.[18,23,30,31] A study

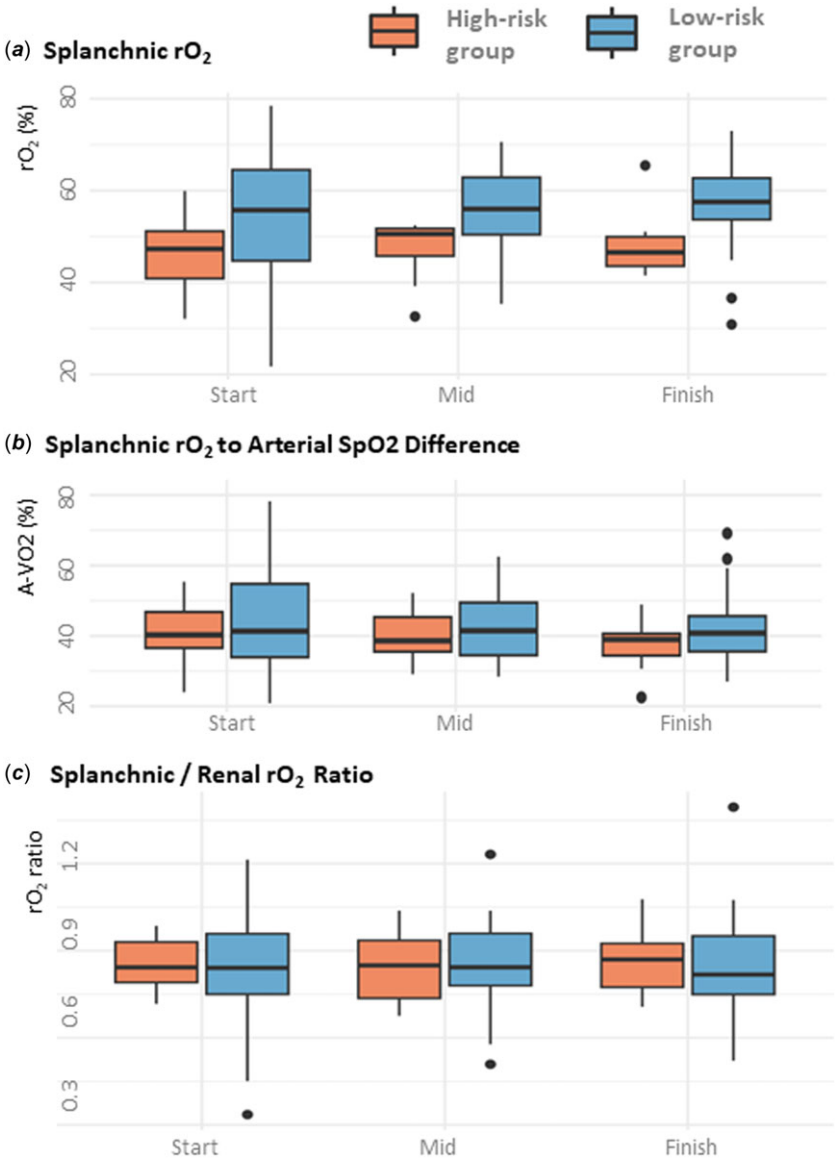

Figure 1. Splanchnic NIRS measures are plotted per risk group at the tested time points during feeds. Central horizontal lines represent the median for the group, boxes represent 25th and 75th interquartile percentiles, vertical lines represent 5th and 95th interquartile percentiles and dot represent outliers (individual patients). Measures include the following: (A) splanchnic rO_2, (B) arterial saturation to splanchnic rO_2 difference (AVO_2), and (C) splanchnic to renal rO_2 ratio. High-risk group (shunt-dependent) presented in orange and low-risk (physiologic repair) in blue.

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in term infants tested 48 hours after congenital heart surgery suggested that low splanchnic regional oxygenation correlates with low gastric pH (through gastric tonometry) and elevated lactates better than renal regional oxygenation.[32] A study from 2014, by DeWitt et al.,[22] looked at splanchnic regional oxygenation in 64 neonates recovering from cardiac surgery in the ICU. The authors showed no significant difference in measured splanchnic regional oxygenation during feeding when comparing 34 infants with single-ventricle palliation to the rest. In their cohort, however, 17% of infants had suspected or confirmed necrotising enterocolitis (all in the single-ventricle group); the infants in this group had lower splanchnic regional oxygenation and spent more time in very low regional oxygenation ranges (< 30%) during feeds. Our goal in this study was to focus on infants who recovered from the critical post-operative phase and are able to tolerate full feeds in an active and awake state. These infants had a lower prevalence of enterocolitis or feeding intolerance and very low regional oxygenation ranges were not observed.

A secondary aim of this study was to examine other splanchnic oxygenation measures that could improve the specificity of detecting changes in splanchnic perfusion: splanchnic AVO2 was calculated as a marker for intestinal oxygen extraction that corrects for hypoxemic state, and splanchnic to renal regional oxygenation index was calculated, theorising that the two values may have negative correlation to each other. While not powered to show significance, a trend of increase in renal regional oxygenation towards the end of feeds was observed in the low-risk group, consistent with the report by DeWitt et al.[22] This trend was not seen for AVO_2 or regional oxygenation index. For the high-risk group, a simultaneous decrease during feeds in regional oxygenation and Standard pulse-oximeter, and thus not in AVO_2. This may suggest that relative venous hypoxaemia is a result of lower systemic saturation only, with no change in delivery or extraction, but this group was small in our cohort, and a combined physiologic change cannot be detected. Lower oxygen availability may still contribute to ischaemia regardless of extraction or delivery rate. The calculation of splanchnic to renal regional oxygenation index is also not suggested to be more sensitive than monitoring splanchnic regional oxygenation alone in our study. The renal and splanchnic regional oxygenation tended to change in the same fashion, which could suggest that changes in total cardiac output are more dominant than relative flow changes or shunting. This theory would be in contrast to the use of splanchnic to cerebral regional oxygenation index in a study by Braski *et al.*[23] that found the index more sensitive than the absolute splanchnic regional oxygenation read to detect changes during feeds in very low birthweight infants with anaemia.

Limitations

This study has the inherent limitations of a small feasibility study with one diagnostic protocol arm and no controls. It is a prospective study that relied on parental consent, which could introduce selection bias. The small cohort was not powered to derive conclusions on the expected splanchnic near-infrared spectroscopy values with feeds. The high- and low-risk groups were not matched in other parameter to remove baseline and illness confounders. It is notable that infants in the high-risk group were tested later after surgery (due to more prolonged ICU stay) and were less anaemic (due to more strict transfusion criteria for single-ventricle heart disease): both could result in improved regional oxygenation with feeds. The high-risk group was also fed higher caloric enteral nutrition (given universally higher caloric needs) that could theoretically increase intestinal demand. Finally, in this study we included infants who were on initial goal feeds and on the acute care unit. It is recognised that using this inclusion criteria the study does not apply to the advancement of feeds to initial goal in the ICU that is also a sensitive time for feeding intolerance and necrotising enterocolitis.

Conclusions

This study joins a growing initiative in inpatient paediatric cardiology to use near-infrared spectroscopy on the acute care floor. We suggest that larger studies could be designed to prove the clinical utility of near-infrared spectroscopy monitoring in tailoring individualised feeding plan and reduce the rate of postoperative intestinal complications.

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Competing interests. None.

Ethical standard. The authors assert that all procedures contributing to this work comply with the ethical standards of the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the Institutional Review Boards at Seattle Children's Hospital, Seattle, Washington, USA.

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