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RESEARCH ARTICLE

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Nurses' perceptions and use of near infrared spectroscopy in paediatric cardiac intensive care

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Abstract

Background: Near-infrared spectroscopy (NIRS) is a non-invasive technology that estimates regional oxygen saturation. Literature demonstrates that NIRS can provide valuable data for clinical staff. However, little research has addressed the nursing care and management of NIRS in the critical care environment.

Aims: To assess nurses' perception around the use of NIRS and current NIRS practice within PCICUs.

Study Design: A 53-item cross-sectional electronic survey was developed to assess indications for NIRS, critical value thresholds and interventions, barriers to use, policies and procedures, and nursing perceptions. Descriptive statistics were used to summarize and aggregate data.

Results: Among the 28 responding sites (63.6% response rate), usage of NIRS was variable and patient-dependent. Most nurses reported using NIRS in patients with unstable physiology such as post-operative single ventricle ($n = 25$, 89.3%) and concern for shock ($n = 21$, 75.0%). Critically low cerebral values varied among respondents from less than 40 ($n = 3$, 10.7%) to less than 60 ($n = 4$, 14.3%), with lower critical values permitted for single ventricle physiology: less than 40 ($n = 8$, 28.6%) to less than 50 ($n = 6$, 21.4%). Reported barriers to using NIRS included skin breakdown ($n = 9$, 32.1%), lack of consistency in decision-making among physicians ($n = 13$, 46.4%), and not using NIRS data when developing a plan of care ($n = 11$, 39.3%). Most ($n = 24$, 85.7%) nurses reported that NIRS provided valuable information and was perceived to be beneficial for patients.

Conclusions: NIRS monitoring is a common technology in the care of complex congenital heart disease patients. Most nurses valued this technology, but inconsistencies and practicalities around its use in guiding patient management were found to be problematic.

Relevance to Clinical Practice: NIRS is commonly used in the PCICU and although nurses perceived NIRS to be useful for their practice, the variability in the interpretation of values and inconsistent protocols and decision-making by physicians was challenging.

KEYWORDS
congenital heart disease, intensive care, near-infrared spectroscopy, nursing, paediatric

1 | INTRODUCTION

1.1 | Background/justification for study

Congenital heart disease (CHD) is the most common birth defect,[1,2] often requiring surgical intervention and subsequent recovery in the specialized paediatric critical care setting. Advancements in care have accelerated in the last several decades and more technologies are being used to support the care of these critically ill patients. Continuous monitoring has become crucial in identifying decompensation, particularly in the postoperative period after cardiac surgery for CHD.[3] One technology being utilized in the paediatric critical care setting is near-infrared spectroscopy (NIRS).[3,4]

NIRS is a non-invasive technology that continuously estimates regional oxygen saturation (rSO_2) for cerebral and somatic locations.[5] Near-infrared light is projected using sensors and measured based on the light transmitted and reflected.[4] The number generated is an estimate of the oxygen supply to the capillary bed in the region of sensor placement.[5] NIRS technology has become standard in many critical care settings caring for patients with CHD, offering a noninvasive method for clinicians to approximate regional tissue oxygen saturation.[6]

NIRS monitors are available at bedsides in addition to telemetry and pulse oximetry monitors. They display both numeric NIRS values and graphic trends. Nurses can adjust the NIRS alarm settings and trend timelines to reflect values consistent with varying oxygenation requirements, such as those with cyanotic CHD who have lower than expected value ranges compared with patients who have structurally normal hearts.[6,7] Regional oxygen saturation values are intended to aid clinicians' decision-making processes, but not be an exclusive diagnostic tool.[5]

Literature demonstrates that NIRS can provide valuable data for clinical staff while caring for critically ill infants and children with CHD. Multiple organ sites can be monitored simultaneously, with cerebral and somatic locations such as peri-renal, hepatic, or mesenteric noted as the most common combinations.[4] Low NIRS values are correlated with longer stays in intensive care and various adverse outcomes.[8] Prolonged low cerebral NIRS values correlate to poor neurodevelopmental outcomes.[9,10] Peri-renal NIRS probes can be used to monitor for acute kidney injury.[11] When placed over the abdomen, low NIRS values have been linked as a potential symptom of necrotizing enterocolitis (NEC) in the neonatal population.[7] Declining NIRS values may also be an earlier indication of impending complications than an increase in serum lactate level on a blood gas.[12] Despite evidence supporting the value of NIRS technology, little research has addressed the nursing care, management, and perceived benefit of NIRS for critically ill paediatric patients with CHD.

What is known about the topic

- Literature demonstrates that NIRS can provide valuable data for clinical staff while caring for critically ill infants and children with CHD.
- NIRS technology has become standard in many critical care settings caring for patients with CHD, offering a noninvasive method for clinicians to approximate regional tissue oxygen saturation.
- Little research has addressed the nursing care and management of NIRS in the critical care environment.

What this paper adds

- This survey provides preliminary evidence of the practice similarities and variabilities among paediatric critical care units utilizing NIRS technology, suggesting value in an international consensus.
- Although nurses reported valuing NIRS data, they reported its limited influence to patient care interventions.
- Standardization of NIRS indications and parameters in the CHD population may improve patient outcomes, reduce adverse events such as skin breakdown, and reduce burden of medical device monitoring for nurses.

1.2 | Objectives

To assess nurses' perception around the use of NIRS and current NIRS practice within PCICUs.

2 | METHODS

2.1 | Study design

This was a cross-sectional, descriptive study of nursing practice associated with NIRS across ICUs in the Consortium of Congenital Cardiac Care-Measurement of Nursing Practice (C4-MNP) international collaborative. Results of this survey were presented according to the e-survey's reporting checklist.

2.2 | Setting/Participants

The C4-MNP is a collaborative of 44 paediatric hospitals in Canada, the United Arab Emirates, and the United States with paediatric

cardiovascular programs that are committed to improving and standardizing nursing practices.[13] The C4-MNP collaborative was established in 2011 with the overarching goal of identifying nursing practices for measurement in the paediatric cardiovascular patient environment. Members from participating hospitals include nurses, advanced practice nurses, nurse administrators, and nurse scientists. Participants in the collaborative were instructed to assign one nurse to respond per institution. The data was collected between July 2020 and August 2020.

2.3 | Variables

A 53-question survey (see Table S1) was developed using content experts, literature, and NIRS manufacturer product information. The survey was broken down into three sections. The first portion of the survey addressed policy, competency, and indications for use of NIRS. The second section covered the care and maintenance of NIRS. Nurses were asked their perceptions of the integration of NIRS into patient care during the third section of the survey. Questions were initially drafted by the authors, feedback was elicited by members of C4-MNP; edits were made to the survey before being piloted via a secure Research Electronic Data Capture (REDCap) database at three institutions to confirm clarity and quality of responses (see Table S1 for complete survey).

2.4 | Data sources/Measurements

The final survey was built with 52 multiple choice and Likert scale questions and one optional, open-ended response. Study data were collected and managed using REDCap electronic data capture tools through the C4-MNP collaborative.[14,15]

This project was exempt from institutional review board review as it was aimed at identifying nursing practice across intensive care units, did not collect any identifiable information from individuals, and not human research. To minimize bias, the survey requested nurse's answers based on the practice in their own unit.

2.5 | Analysis

Data were cleaned to ensure that no more than one survey was included per institution. Two institutions sent duplicate surveys; therefore, according to the policy of the C4-MNP collaborative, the survey submitted by the most senior nurse was included in the data analysis. Descriptive statistics were calculated for each of the 52 required survey items and summarized. An optional, open-ended question at the end of the survey allowed participants to provide final comments to inform the collaborative of interest in the topic and potential next steps but was not formally analysed.

TABLE 1 Demographics ($n = 28$)

	Frequency (%)
Respondent's primary unit type	
CICU	24 (85.7)
Mixed ICU	3 (10.7)
PICU	1 (3.6)
Number of unit beds	
1–10	0 (0.0)
11–20	12 (42.9)
21–30	11 (39.3)
31–40	4 (14.3)
41+	1 (3.6)
Environment in which your institution uses NIRS	
NICU	10 (35.7)
CICU	26 (92.9)
PICU	18 (64.3)
Stepdown units	2 (7.1)
Cath lab	9 (32.1)
Operating room	19 (67.9)
Respondent's current job title	
Staff nurse	6 (21.4)
Clinical nurse specialist	7 (25.0)
Nurse educator	7 (25.0)
Nurse practitioner	1 (3.6)
Nurse scientist	0 (0.0)
Nursing administrator	2 (7.1)
Other	5 (17.9)
Respondent's years of nursing experience	
<1 year	0 (0.0)
1–4 years	0 (0.0)
5–9 years	5 (17.9)
10–14 years	7 (25.0)
>15 years	16 (57.1)
Respondent's years in current position	
<1 year	1 (3.6)
1–4 years	11 (39.3)
5–9 years	6 (21.4)
10–14 years	4 (14.3)
>15 years	6 (21.4)

3 | RESULTS

Out of 44 institutions invited to participate, 28 institutions responded to the survey, resulting in a 63.6% response rate. Those who responded completed the survey in its entirety. Out of the 28 respondents who participated for their institution, 85.7% ($n = 24$) were from a CICU, 10.7% ($n = 3$) were from mixed ICUs, and 3.6% ($n = 1$) were from a PICU. The majority of institutions were based in the United States

($n = 27$, 96.4%) and one was from the United Arab Emirates (3.6%). For a full description of the site and participant demographics, see Table 1.

All (100%) of the participating institutions reported using NIRS in their ICUs, with 67.9% ($n = 19$) using the same brand of monitor. For 67.9% of institutions ($n = 19$), NIRS had been used for 5 years or more. About two-thirds of nurses ($n = 19$, 67.9%) reported that their institutions had guidelines or policies regarding the general management of NIRS which stated that nurses were responsible for NIRS documentation and equipment. Of these, the vast majority of nurses ($n = 18$, 94.7%) reported that those policies and guidelines were based on manufacturer guidelines. Nursing knowledge of NIRS was not evaluated by 57.1% ($n = 16$) of institutions. A single competency-assessed nursing knowledge at 42.9% ($n = 12$) of institutions, and no institutions reported annual competency assessments. Documentation of NIRS values was manually entered in the electronic medical record (EMR) by 42.9% ($n = 12$) of nurses, not charted in the EMR at 17.9% ($n = 5$) of institutions, and automatically entered in the EMR via software interfacing at 39.2% ($n = 11$) of institutions.

3.1 | Policy, competency, and indications for NIRS

The majority ($n = 25$, 89.3%) of respondents reported the use of both cerebral and peri-renal somatic NIRS probes. Other uses included: cerebral only ($n = 3$, 10.7%), somatic/peri-renal only ($n = 2$, 7.1%), other somatic regions ($n = 2$, 7.1%), cerebral/somatic/abdominal ($n = 1$, 3.6%), and diagnosis dependent ($n = 2$, 7.1%). Nurses reported the top five clinical indications for NIRS were for hemodynamically unstable patients regardless of cardiac physiology: post-operative single ventricle physiology ($n = 25$, 89.3%), post-operative biventricular physiology ($n = 22$, 78.6%), post-cardiac arrest ($n = 24$, 85.7%), extracorporeal membrane oxygenation ($n = 24$, 85.7%), and concern for shock and low cardiac output ($n = 21$, 75.0%) (Table 2). Conversely, some nurses noted that NIRS were not routinely used for those with planned early postoperative extubations ($n = 7$, 25%), those who underwent cardiac catheterization ($n = 15$, 53.6%) or lymphatic interventions ($n = 6$, 21.4%), and those who did not require cardiopulmonary bypass in the operating room ($n = 3$, 10.7%). The ages of patients monitored with NIRS were reported as the following: premature infants ($n = 22$, 78.6%), full-term infants ($n = 28$, 100%), toddlers ($n = 27$, 96.4%), school age ($n = 26$, 92.9%), adolescents ($n = 25$, 89.3%), adults ($n = 22$, 78.6%).

TABLE 2 Clinical indications for use of NIRS ($n = 28$)

Indication	Frequency (%)
Post-operative single- ventricle physiology	25 (89.3)
Post-cardiac arrest	24 (85.7)
ECMO	24 (85.7)
Post-operative biventricular physiology	22 (78.6)
Concern for circulatory compromise (e.g. shock) and low cardiac output	21 (75.0)
Preoperative patients with ductal-dependent defects on prostaglandins	15 (53.6)
Heart failure	13 (46.4)
Monitoring during natural PDA closure off prostaglandins	11 (39.3)
Patient's requiring inotropes	11 (39.3)
Standard of care	11 (39.3)
Post-catheterization	8 (28.6)
Necrotizing enterocolitis	6 (21.4)
Clinical prenatal diagnosis for Special Delivery Units	5 (17.9)
Anaemia	3 (10.7)
Concern for seizures	3 (10.7)
Gestational age <28 weeks	2 (7.1)
Other diagnoses	2 (7.1)
Hydrocephalus	0 (0.0)

For both single ventricle and biventricular patients, almost one quarter ($n = 6$, 21.4%) of respondents reported no critical low values and values varied across sites (Figure 1). Respondents that reported other critical values besides discrete numbers expanded in a free text section which yielded the following responses: percent decrease for low values, values decreased greater than 20% from baseline for low values, physician specific for low values, and trend-based for both high and low values. When queried specifically about the trended analysis of NIRS values, the majority of nurses ($n = 22$, 78.6%) answered that analysis was always or often performed over time. Most nurses reported that critical values ($n = 19$, 67.9%) and changes in values ($n = 21$, 75.0%) were always or often discussed with the clinical team and with oncoming nurses during patient handoff ($n = 24$, 85.7%). Nurses reported that physicians only sometimes ($n = 7$, 25%) or never ($n = 12$, 42.9%) wrote orders to be notified of critical high and low NIRS alarms.

Only one respondent (3.6%) reported that medications were always or often adjusted in response to NIRS values, and 67.9% ($n = 19$) stated they were sometimes adjusted. The medications reported to be adjusted were inotropes ($n = 19$, 67.9%), sedation ($n = 14$, 50%), analgesics ($n = 9$, 32.1%), paralytics ($n = 7$, 25%), fluid boluses ($n = 1$, 3.6%) or antiarrhythmics ($n = 1$, 3.6%). Additionally, 85.7% ($n = 24$) of nurses reported that physicians never wrote standing orders for the administration of medications in response to critical high and low NIRS alarms. No nurses reported adjustments to ventilator settings in response to NIRS values as often or always, and 71.4% ($n = 20$) reported sometimes observing adjustments to these settings.

3.2 | Care and maintenance of NIRS

Nurses reported that NIRS are used for various time periods, including 24 h ($n = 4$, 14.3%), 48 h ($n = 6$, 21.4%), 72 h ($n = 7$, 25%), or more than 72 h ($n = 12$, 42.9%). Variation in the duration of usage was reported to vary by physician ($n = 11$, 39.3%), nurse ($n = 2$, 7.1%), and clinical indication ($n = 15$, 53.6%) or not determined by a specific time period ($n = 10$, 35.7%). In the postoperative period, nurses reported that NIRS remains in place for 1–3 days ($n = 14$, 50%), 4–7 days

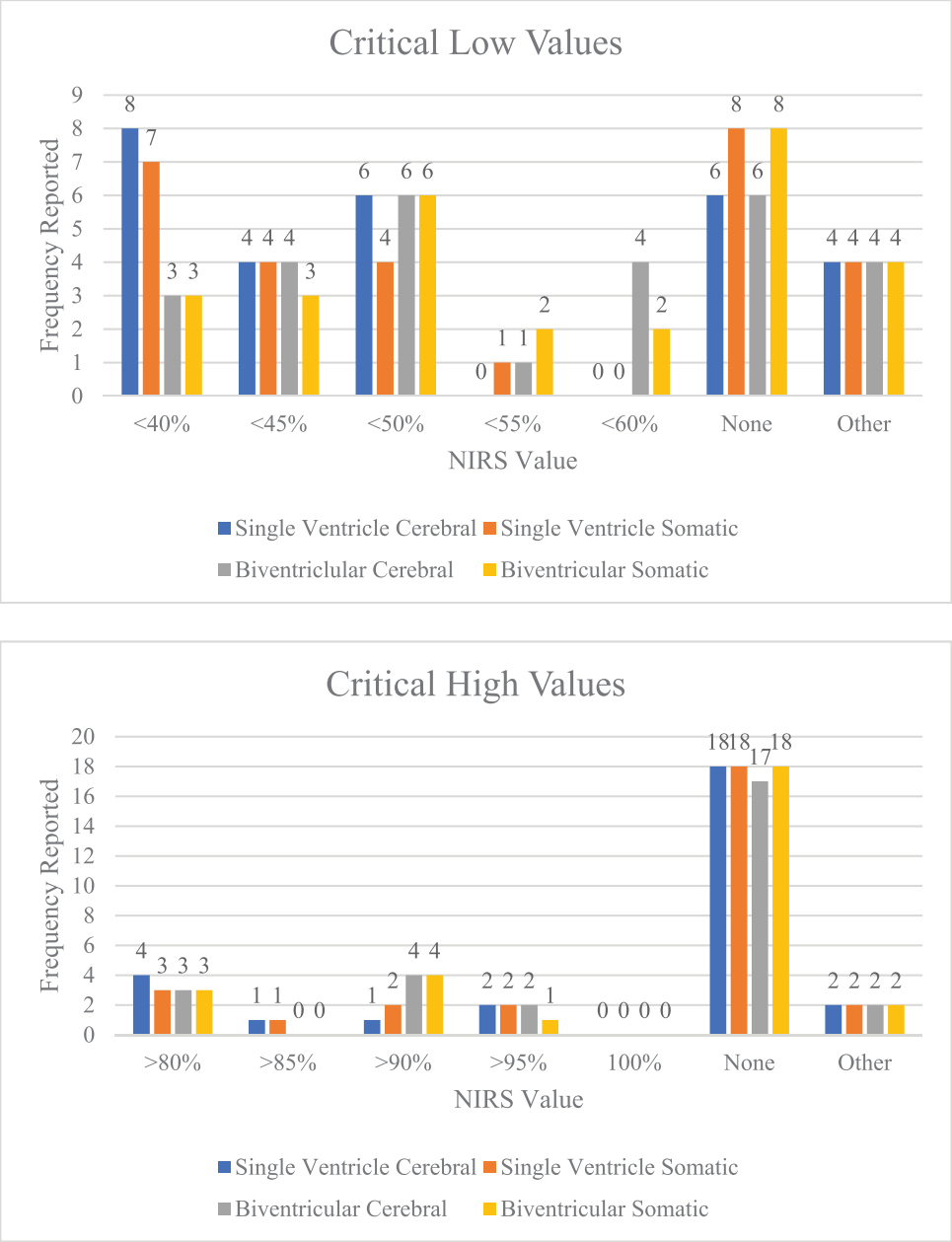

FIGURE 1 Critical low and high values for NIRS

(n = 8, 28.6%), over 15 days (n = 2, 7.1%), or varied by physician (n = 4, 14.3%). Additionally, 60.7% (n = 17) of nurses reported that the length of time NIRS is used differs based on the type of surgery or diagnosis.

Probe rotation was reported across a wide range, every 4 h (n = 1, 3.6%), 12 h (n = 1, 2.6%), 24 h (n = 3, 10.7%), 48 h (n = 6, 21.4%), or no rotation at all (n = 11, 39.3%). Of the six (21.4%) respondents that answered, "other duration", five nurses expanded in a free text section listing a rotation frequency of every 5–7 days, as needed, every 2 h, once per shift, or every 72 h. Probe replacement ranged between every 24 h (n = 2, 7.1%), every 48 h (n = 6, 21.4%), every 72 h (n = 5, 17.8%), every 5–7 days (n = 3, 10.7%), or no routine replacement (n = 10, 35.7%). Two nurses (7.1%) responded as "other duration" and commented that the probe was either replaced as needed or that the probe was not reused and changed with rotation. Nurses documented both probe rotation and replacement 25% (n = 7) of the time, neither 35.7% (n = 10) of the time and rotation and replacement 7.1% (n = 2) and 32.1% (n = 9) respectively.

Skin protectant was used under NIRS probes in over one-third (n = 11, 39.3%) of institutions, yet variation existed as to the type of protectant used. Nurses reported the following top five barriers affecting the use of nursing practice with NIRS: no consistency among physicians (n = 13, 46.4%), physicians not using the data when developing plan of care (n = 11, 39.3%), limited available skin area (n = 9, 32.1%), skin breakdown or injury from probes (n = 9, 32.1%), and difficulty adhering to skin (n = 8, 28.6%) (Table 3).

TABLE 3 Barriers affecting use of nursing practice with NIRS ($n = 28$)

Barrier	Frequency (%)
No consistency in decision-making among physicians	13 (46.4)
Physicians do not use the data when developing plan of care	11 (39.3)
Skin breakdown or injury from probes	9 (32.1)
Limited available skin area	9 (32.1)
Difficulty adhering to skin	8 (28.6)
Lack of policies at my institution	6 (21.4)
NIRS values do not tend to inform my nursing practices	4 (14.3)
Lack of NIRS-specific education/training	4 (14.3)
None	4 (14.3)
Added workload	2 (7.1)
Constant troubleshooting	2 (7.1)

3.3 | Nursing integration of NIRS

Most ($n = 24$, 85.7%) agreed or strongly agreed that NIRS provides valuable information for nursing assessment and interventions and most ($n = 25$, 89.2%) reported NIRS technology is beneficial to the patient. The majority of nurses ($n = 23$, 82.1%) felt competent in their interpretation of NIRS values and 75% ($n = 21$) were neutral or disagreed that NIRS added to their nursing workload.

4 | DISCUSSION

To our knowledge, this is the first description of nursing practice of NIRS in the paediatric ICU setting. Though all nurses reported using NIRS at the institutions we surveyed, they demonstrated wide variation in practice across institutions caring for paediatric patients with CHD, similar to the variation demonstrated among paediatric populations across European PCICUs.[16] Consistent with other studies, variation in practice was found in the indications for use, probe placements, and how NIRS values informed patient care.[16] Almost half of nurses reported lack of consistency among physicians with respect to interventions based on changes in NIRS. Although some variation was found regarding NIRS sensor placement, the placement sites including cerebral, peri-renal, and abdominal monitoring were consistent with the literature.[7,16] Most nurses reported having discussions about the plan of care with physicians and other nurses when observing changes in NIRS values. However, despite discussing value changes, nurses reported that NIRS values did little to influence patient care interventions such as adjusting medications manipulating ventilator settings, or developing the patient's plan of care. More research is needed to identify thresholds, trends, or critical values for specific defect types to improve the utility of NIRS in supporting patient care.

Although approximately two-thirds of nurses reported that their institutions had policies or guidelines for NIRS, the vast majority were cited as manufacturer guidelines specific to the brand used at each nurses' institution. Guidelines such as these would provide information about the machine itself, but not provide instructions or policies regarding how to use NIRS data to manage or care for a patient with CHD physiology. In a recent survey of European PCICUs, Hoskote et al.[16] similarly found that a majority of institutions did not have a protocol or guideline for NIRS specific to the PCICU setting.

The majority of nurses reported that NIRS is used widely for conditions related to low cardiac output. Nonetheless, there was not agreement among participating nurses regarding which NIRS values were deemed critical low values for both single ventricle and two ventricle physiologies (Figure 1). Of those that provided values, responses were as expected, demonstrating trends towards critical values of single ventricle physiology that were the same or lower than those for biventricular physiology, based inherently on the overall lower oxygen saturations of those with single ventricle physiologies.[6]

Although most nurses acknowledged following NIRS trends, there was not a consensus regarding the length of time that NIRS was used for patients or how long NIRS was utilized in the postoperative period. We also found variation in practice in the timing of NIRS probe rotation and use of skin protectant. These are new findings, as previous studies have not explored these aspects of nursing care.[16] Importantly, one-third of nurses reported skin breakdown or injury from probes as a barrier to the use of NIRS. This is not surprising, since research has established that paediatric patients are at risk for device-related pressure injuries.[17] However, we were unable to find any literature reporting skin integrity problems specifically resulting from the utilization of NIRS technology.

4.1 | Limitations

Our study design using survey-based reporting from nurses regarding unit-based nursing practice has inherent limitations. Study results were limited to institutions within the C4-MNP collaborative, which may have generated selection bias. The survey was distributed during the COVID-19 pandemic, which may have negatively influenced the response rate of below the optimal response rate of 70%. Furthermore, with the survey showing 100% use of NIRS, institutions who do not use NIRS may not have responded to the survey, also potentially influencing our response rate. Since we targeted only one nurse per institution, the study did not examine the potential variability in practice that may occur within each institution. The survey did not ask for nurses to upload institution guidelines to see if the respondent nurses' views reflect the unit policies.

4.2 | Recommendations & implications for practice and further research

Our findings are relevant to the nursing practice of NIRS with critically ill patients who have CHD and address an important gap in the

current literature available describing nursing practice of NIRS in paediatric CHD. Bedside nurses are primarily responsible for the daily management of NIRS monitors. As with any medical device, initial competency training and ongoing education are essential to support nursing care. Yet, a portion of surveyed nurses reported a lack of NIRS-specific education and training. Our findings indicate a critical need to develop a nursing standard of care and develop unit-based education for NIRS monitoring. The role of nurses should include the development of policies and procedures regarding the management of devices used in patient care.[18] By involving nurses in the standardization of care, nurses can better prevent patient harm and serve as advocates for their patients.

As our results demonstrated, nurses value the information that NIRS provides and believe it is beneficial to their patients. This is important as nurses bring a complementary perspective to the multidisciplinary management of NIRS technology which has been embraced as important by many PCICUs.[16] Nurses can target the reported barriers identified in our study to work with their hospitals to improve consistency in care. Standardizing care may improve how the NIRS values inform patient care to improve outcomes, and, when NIRS is not needed, may reduce the burden of medical device monitoring for nurses and reduce the risk of adverse events to patients, such as skin breakdown. Previous research on NIRS has not addressed skin injury and there are limited manufacturer guidelines related to skin protection and probe rotation. Due to reported concerns with skin integrity, further research is recommended to develop standardized skin protection measures.

More research is needed to determine whether the variation we found in the reported critical values of NIRS can be attributed to differences in manufacturer guidelines, clinician preference, or other reasons. Nonetheless, our findings are consistent with previous reports of variability in target NIRS values for patients cared for in European PCICUs.[16] Utilization of NIRS in this unique population necessitates further inquiry among international counterparts to guide the designation of critical thresholds for these patients, accounting for the differences between single ventricle and two ventricle physiologies and cyanotic and acyanotic patients. This is particularly important due to the varying degrees of correlations found across age ranges and different locations between NIRS values and venous oxygen saturations.[3,19–22] Studies should also examine the use of NIRS values in the management of patients and determining their plans of care using machine learning strategies or other innovative methods that can support the development of standardized interventions to improve patient outcomes. Future research should also examine the link between nursing practice of NIRS and patient outcomes. More research is needed to determine the risk of NIRS specifically for skin breakdown and to identify whether patients with CHD are more at risk for experiencing skin breakdown from NIRS. Furthermore, clinical trials are needed to test the efficacy of interventions targeting the prevention of skin breakdown with NIRS.

5 | CONCLUSIONS

This contemporaneous description demonstrates the variation of practice among paediatric critical care units utilizing NIRS technology. Although in our small study NIRS was perceived to be a highly valued technology, changes in NIRS values did not appear to routinely influence patient care interventions, and practices varied among participating institutions. This study highlights the need for international evidence-based standards of care for nurses utilizing NIRS in their care of critically ill children.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from C4-MNP. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from Dr. Jean Connor with the permission of C4-MNP.

ETHICS STATEMENT

This project was exempt from Institutional Review Board review as it was aimed at identifying nursing practice across intensive care units, did not collect any identifiable information from individuals, and not human subject research.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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