Identification of Low Cardiac Output Syndrome at the Bedside: A Pediatric Cardiac Intensive Care Unit Survey

Matthew J. Nordness, BSN, RN
Ashly C. Westrick, MPH
Heidi Chen, PhD
Mark A. Clay, MD

BACKGROUND Low cardiac output syndrome is a transient constellation of signs and symptoms that indicate the heart's inability to supply sufficient oxygen to tissues and end-organs to meet metabolic demand. Because the term lacks a standard clinical definition, the bedside diagnosis of this syndrome can be difficult.
OBJECTIVE To evaluate concordance among pediatric cardiac intensive care unit nurses in their identification of low cardiac output syndrome in pediatric patients after cardiac surgery.
METHODS An anonymous survey was distributed to 69 pediatric cardiac intensive care unit nurses. The survey described 10 randomly selected patients aged 6 months or younger who had undergone corrective or palliative cardiac surgery at a freestanding children's hospital in a tertiary academic center. For each patient, data were presented corresponding to 5 time points (0, 6, 12, 18, and 24 hours postoperatively). The respondent was asked to indicate whether the patient had low cardiac output syndrome (yes or no) at each time point on the basis of the data presented.
RESULTS The response rate was 46% (32 of 69 nurses). The overall Fleiss κ value was 0.30, indicating fair agreement among raters. When the results were analyzed by years of experience, agreement remained only slight to fair.
CONCLUSIONS Regardless of years of experience, nurses have difficulty agreeing on the presence of low cardiac output syndrome. Further research is needed to determine whether the development of objective guidelines could improve recognition and facilitate communication between the pediatric cardiac intensive care unit nurse and the medical team. (*Critical Care Nurse*. 2019;39[2]:e1-e7)

CE 1.0 hour, CERP A

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1. Review current literature and clinical diagnostic criteria for low cardiac output syndrome (LCOS) in pediatric patients
2. Analyze concordance of LCOS diagnosis among pediatric cardiac intensive care nurses at a tertiary referral pediatric center
3. Identify LCOS in pediatric patients after palliative or corrective cardiac surgery

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 doi:https://doi.org/10.4037/ccn2019794

Low cardiac output syndrome (LCOS) is the leading cause of morbidity and mortality in pediatric patients after cardiac surgery.[1,2] Wernovsky et al[3] reported the presence of LCOS in as many as 25% of infants who had undergone an arterial switch operation, with the cardiac index lowest at 9 to 12 hours postoperatively. Early recognition of this common and severe complication of cardiac surgery is crucial. For up to 12 hours, bedside nurses play a vital role in recognizing the subtle symptoms of LCOS and reporting its insidious onset to the medical team. These nurses are in a position to witness minute-by-minute changes in the patient's status, enabling early detection of LCOS, which may otherwise be missed.

Low cardiac output syndrome is a transient constellation of signs and symptoms indicating the inability of the heart to deliver sufficient oxygen to tissues and end organs to meet metabolic demand.[4,5] Objective measurements commonly used as surrogates to establish the presence of LCOS include heart rate, blood pressure, central venous pressure, near-infrared spectroscopy (NIRS), urine output, and serum lactate level.[4,5] Despite the abundance of clinical measurements, LCOS remains difficult to identify and characterize without more costly and invasive measures.[4,6-8] It is crucial that clinical measurements provoke a standardized and cohesive response by nurses, who then document the necessary data and report it to the medical team. The purpose of this study was to evaluate concordance among pediatric cardiac intensive care unit (PCICU) nurses in their identification of LCOS in pediatric patients after cardiac surgery.

LCOS is a transient constellation of signs and symptoms indicating the inability of the heart to deliver sufficient oxygen to tissues and end organs to meet metabolic demand.

Methods

Participants and Setting

The study protocol was approved by the university institutional review board. A survey on LCOS was created and distributed anonymously to all 69 PCICU nurses employed at a freestanding children's hospital in a tertiary academic center with an independent 18-bed PCICU. The study data were collected and managed using research electronic data capture (REDCap).[9] REDCap is a secure, web-based application designed to support data capture for research studies, providing (1) an intuitive interface for validated data entry, (2) audit trails for tracking data manipulation and export procedures, (3) automated export procedures for seamless data downloads to common statistical packages, and (4) procedures for importing data from external sources.

Study Design

We accessed the Credentials Application Tracking System at our institution and collected data on the total years of experience of all 69 PCICU nurses to whom the survey was distributed. Level of experience was split into 4 categories: less than 2 years, 2 to 4.9 years, 5 to 9.9 years, and 10 years or more. All PCICU nurses received an email with a link to the REDCap survey and were given 12 days to complete the survey. They also received several emails (survey days 1, 7, 9, 10, 11, and 12) with reminders designed to maximize participation. Participants were first asked to indicate their level of nursing experience. The survey then presented 10 clinical scenarios. Each scenario involved a patient aged 6 months or less who had undergone corrective or palliative cardiac surgery at our institution between 2010 and 2016 (this period was chosen because of its stability in cardiothoracic surgical staffing). The cardiothoracic surgical database had been randomly queried for 10 patients who fit the aforementioned inclusion criteria. For each patient, a brief history and diagnoses were presented (Table 1). Then, clinical data for

Authors

Matthew J. Nordness is a first-year medical student at the Vanderbilt University School of Medicine, Nashville, Tennessee. At the time this work was performed, he was a registered nurse in the pediatric cardiac intensive care unit at the Monroe Carell Jr Children's Hospital at Vanderbilt.

Ashly C. Westrick is a graduate student, University of Miami, Miami, Florida. At the time this work was performed, she was a site manager, Vanderbilt University Medical Center, and a clinical research coordinator for Surgical Outcomes Center for Kids Nashville, Tennessee.

Heidi Chen is a research assistant professor of biostatistics, Vanderbilt University School of Medicine, Nashville, Tennessee.

Mark A. Clay is an assistant professor of pediatrics, Division of Critical Care Medicine, Department of Pediatrics at Vanderbilt University School of Medicine.

Corresponding author: Mark A. Clay, MD, Division of Cardiology and Critical Care, Monroe Carell Jr. Children's Hospital at Vanderbilt, 2200 Children's Way, 5121 Doctors' Office Tower, Nashville, TN 37232-9075 (email: mark.a.clay@vanderbilt.edu).

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Table 1 Characteristics, diagnoses and surgical procedures of patients

Patient	Sex	Age	Weight, kg	Diagnosis	Surgery
1	F	10 d	3.89	Pulmonary atresia/VSD	Pulmonary artery reconstruction and left modified BT shunt
2	F	2 d	3.11	HLHS (mitral and aortic atresia)	Norwood/Sano procedure (6 mm)
3	M	14 d	2.67	Tricuspid stenosis, pulmonary atresia, and coronary sinusoids	PDA ligation and placement of 3.5-mm right modified BT shunt
4	M	6 mo	5.80	Complete AVSD	AVSD repair
5	F	2 mo	4.40	Tetralogy of Fallot with supravalvar, valvar, and subvalvar pulmonary stenosis	VSD closure, pulmonary valvectomy with transannular patch
6	F	13 d	3.66	Coarctation and VSD	Coarctation repair and VSD closure
7	M	4.5 mo	6.70	Tricuspid atresia after Norwood	Bidirectional Glenn operation, right coronary sinus unroofing, atrial septectomy, and pulmonary artery band
8	M	5 d	3.20	Pulmonary atresia and VSD with ductal-dependent pulmonary blood flow	9-mm RV-PA homograft, VSD closure, tricuspid valvuloplasty, and partial ASD closure
9	F	4 d	3.50	HLHS (mitral atresia and aortic atresia) and restrictive atrial septum	Norwood procedure with 3.5-mm BT shunt and ligation and division of PDA
10	F	23 d	2.00	D-transposition of the great arteries with intact ventricular septum	Arterial switch with LeCompte maneuver, repair of ASD, and division of PDA

Abbreviations: ASD, atrial septal defect; AVSD, atrioventricular septal defect; BT, Blalock-Taussig; HLHS, hypoplastic left heart syndrome; PA, pulmonary artery; PDA, patent ductus arteriosus; RV, right ventricular; VSD, ventricular septal defect.

5 time points (0, 6, 12, 18, and 24 hours postoperatively) for that patient were presented: vital signs (temperature, heart rate, respiratory rate, oxygen saturation, arterial blood pressure), arterial blood gas values, fraction of inspired oxygen, urine output, dorsalis pedis pulse strength (as documented by the bedside nurse), serum lactate level, and NIRS. All data were retrieved from our institution's electronic health record. For each time point, the respondent was asked to indicate whether the patient had low cardiac output on the basis of the clinical data presented for that time (yes or no). A sample patient scenario with full clinical data is shown in Table 2.

In the absence of widely accepted criteria for LCOS, this study used criteria similar to those used by Hoffman et al[10] in the PRIMACORP (Prophylactic Intravenous Use of Milrinone After Cardiac Operation in Pediatrics) study. In that study, the presence of metabolic acidosis was the sine qua non for the diagnosis of LCOS.[10] The criteria used for LCOS in our study included the following clinical signs and symptoms: tachycardia (heart rate > 180/min), oliguria (urine output < 0.5 mL/kg per hour), weak peripheral pulses (a surrogate for poor peripheral perfusion), cardiac arrest, a difference of 30 points or more in arterial versus mixed venous oxygen saturation (with NIRS used as a surrogate for systemic venous saturation), and metabolic acidosis (indicated by an increased base deficit > 4 or a lactate level > 2 mg/dL).[10-15] For a positive diagnosis of LCOS, the patient had to meet at least 1 of the 2 definitions of metabolic acidosis, plus 1 other criterion. Using these criteria, an "answer key" was developed indicating yes or no for whether the patient was experiencing LCOS at each time point.

Statistical Analysis

Agreement among nurses was measured with Fleiss κ. Agreement for each nurse with the "answer key" was measured with Cohen κ. Two-way analysis of variance (ANOVA) was used to evaluate the impact of nursing experience and time points on the κ agreement. A κ value of 0.20 or less indicates slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, good agreement; and 0.81 to 1.00, very good agreement.

Results

The overall survey response rate was 46% (32 of 69 nurses). Nurses with less than 2 years of experience had the lowest response rate, 24% (6 of 25 nurses). Nurses with 2 to 4.9 years of experience had the highest response rate, 75% (12 of 16 nurses). Nurses with 5 to 9.9 years of

Table 2 Sample patient scenario with clinical data from the first 24 postoperative hours[a]

Postoperative hour	Temperature, °C	Heart rate, beats/min	Respiratory rate, breaths/min	Blood pressure (systolic/diastolic), MAP, mm Hg	Oxygen saturation/FIO_2
0	33.3	144	38	83/48, 63	73/0.65
6	36.1	179	28	83/54, 68	89/0.30
12	36.3	167	28	72/34, 47	82/0.21
18	37.1	148	30	73/38, 48	85/0.21
24	36.9	139	24	67/30, 41	82/0.21

Abbreviations: ABG, arterial blood gas; BE, base excess/deficit; FIO_2, fraction of inspired oxygen; MAP, mean arterial pressure; NIRS, near-infrared spectroscopy.
[a] 10-day-old, 3.89-kg infant with pulmonary atresia/ventricular septal defect after pulmonary artery reconstruction and left modified Blalock-Taussig shunt.
[b] Dorsalis pedis pulse, 1+/weak.

Table 3 Agreement by level of experience

Nursing experience, y	Agreement among nurses κ[a]	Agreement among nurses 95% CI	Agreement with answer key κ[a]	Agreement with answer key 95% CI
<2	0.24	0.17-0.32	0.23	0.11-0.36
2-4.9	0.34	0.31-0.38	0.28	0.21-0.35
5-9.9	0.28	0.23-0.34	0.33	0.23-0.42
≥10	0.25	0.18-0.33	0.20	0.08-0.32

[a] Kappa interpretation: slight agreement, 0.20 or less; fair agreement, 0.21 to 0.40; moderate agreement, 0.41 to 0.60; good agreement, 0.61 to 0.80; very good agreement, 0.81 to 1.00.

experience had a response rate of 44% (8 of 18 nurses). Nurses with 10 or more years of experience had a response rate of 60% (6 of 10 nurses).

Agreement Among Nurses

The overall Fleiss κ value among nurses was 0.30 (95% CI, 0.29-0.31), indicating fair interrater agreement. Fair agreement existed across all experience categories (Table 3). Experience level had no effect on agreement among nurses, with 2-way ANOVA comparing agreement among nurses at the various experience levels showing no statistically significant differences (Table 4). Agreement among nurses by time point was also slight to fair for all hours except hour 18, when the κ value (0.44) indicated moderate agreement (Table 5). In the 2-way ANOVA comparing

Table 4 Two-way analysis of variance for agreement among nurses

	Reference	β	95% CI	*P*
Intercept		0.123	-0.01 to 0.256	.09
Practice years B[a]	Practice years A[b]	0.094	-0.038 to 0.226	.19
Practice years C[c]	Practice years A[b]	0.038	-0.094 to 0.17	.58
Practice years D[d]	Practice years A[b]	-0.042	-0.174 to 0.09	.54
Time 6 hours	Time 0 hours	0.098	-0.05 to 0.245	.22
Time 12 hours	Time 0 hours	0.085	-0.063 to 0.233	.28
Time 18 hours	Time 0 hours	0.267	0.12 to 0.415	.004
Time 24 hours	Time 0 hours	0.118	-0.03 to 0.265	.14

[a] Nurses with 2-4.9 years of experience.
[b] Nurses with <2 years of experience.
[c] Nurses with 5-9.9 years of experience.
[d] Nurses with ≥10 years of experience.

NIRS (left cerebral/right cerebral/somatic)	Vasoactive drugs (calcium chloride, epinephrine, vasopressin)	ABG values (pH/Pco_2/Po_2/BE)[b]	Lactate, mg/dL	Urine output, mL/kg per h
36/31/78	20 mg/kg per h, 0.075 µg/kg per min, 0.01 U/kg per h	7.32/69/36/6.3	3.0	0
51/39/74	20 mg/kg per h, 0.08 µg/kg per min, 0.04 U/kg per h	7.39/41/41/-0.2	3.4	6.7
54/46/73	5 mg/kg per h, 0.05 µg/kg per min, 0.02 U/kg per h	7.41/35/40/-1.8	2.8	4.2
54/46/69	5 mg/kg per h, 0.02 µg/kg per min, 0.02 U/kg per h	7.40/41/34/0.5	0.9	0.94
59/46/68	15 mg/kg per h, 0.02 µg/kg per min, 0.02 U/kg per h	7.35/56/30/3.9	1.4	1.97

agreement among nurses at the various time points, a statistically significant difference was found only between 0 hours and 18 hours ($P = .004$; Table 4). The overall agreement among nurses returned to fair at the 24-hour time point (Table 5).

Nurse Agreement With "Answer Key"

Experience level had no effect on nurse agreement with the "answer key." Assessment of respondent agreement with the "answer key" by level of experience showed slight to fair agreement (Table 3). In the 2-way ANOVA comparing nurse agreement with the "answer key" at the various experience levels, no statistically significant differences were found (Table 6). In assessment of respondent agreement with the "answer key" by time point, agreement

Table 5 Agreement by time point

	Agreement among nurses		Agreement with answer key	
Time, h	κ[a]	95% CI	κ[a]	95% CI
0	0.18	0.15-0.21	0.20	0.07-0.34
6	0.27	0.25-0.3	0.27	0.18-0.35
12	0.26	0.23-0.29	0.09	0.00-0.18
18	0.44	0.41-0.47	0.49	0.41-0.58
24	0.30	0.27-0.33	0.29	0.22-0.36

[a] Kappa interpretation: slight agreement, 0.20 or less; fair agreement, 0.21 to 0.40; moderate agreement, 0.41 to 0.60; good agreement, 0.61 to 0.80; very good agreement, 0.81 to 1.00.

Table 6 Two-way analysis of variance for nurse agreement with answer key

	Reference	β	95% CI	*P*
Intercept		0.169	0.025 to 0.314	.02
Practice years B[a]	Practice years A[b]	0.045	-0.101 to 0.191	.54
Practice years C[c]	Practice years A[b]	0.093	-0.065 to 0.251	.26
Practice years D[d]	Practice years A[b]	-0.033	-0.202 to 0.136	.70
Time 6 hours	Time 0 hours	0.066	-0.063 to 0.195	.32
Time 12 hours	Time 0 hours	-0.114	-0.243 to 0.015	.08
Time 18 hours	Time 0 hours	0.289	0.16 to 0.418	<.001
Time 24 hours	Time 0 hours	0.085	-0.044 to 0.214	.20

[a] Nurses with 2-4.9 years of experience.
[b] Nurses with <2 years of experience.
[c] Nurses with 5-9.9 years of experience.
[d] Nurses with ≥10 years of experience.

was slight to fair except at hour 18 (Table 5), when the κ value (0.49) indicated moderate agreement. In the 2-way ANOVA comparing nurse agreement with the "answer key" for the various time points, a statistically significant difference was found only between 0 hours and 18 hours ($P < .001$; Table 6). At 24 hours, agreement returned to fair (Table 5).

Discussion

Nurses act as a bridge between the patient and the medical team, relaying critical clinical information to other health care providers. Many different clinical measurements have been used in an attempt to determine the presence of LCOS. This variation is probably responsible for the significant differences in interpretation at the bedside. No single bedside measurement is available that definitively correlates with LCOS in the pediatric cardiac population. Therefore, nurses must sift through multiple data points and be able to recognize subtle symptoms that might indicate LCOS. In the absence of a standard definition or a validated scoring system, nurse-to-nurse interpretation may vary widely. Nurses are on the frontlines of caring for these critically ill patients, who can experience transient changes in cardiac output; however, literature on nursing bedside evaluation of LCOS is scarce. The results of our survey should bring attention to this void in the nursing literature and raise awareness of the need for further research and education in this area.

An LCOS scoring system might be the best method of increasing nursing bedside recognition of symptoms, facilitating communication with the medical team, and subsequently improving patient outcomes.

Although some studies have been conducted that systematically approached the definition of LCOS, they were led by physicians and did not take into account the unique perspective of the bedside nurse. Several scoring systems have been created that are designed to evaluate patients for the condition and predict poor outcomes in the postoperative period.[16,17] Ulate et al[17] developed an LCOS score that used specific criteria to identify LCOS; they found the score to be useful as a predictor of morbidity and resource use in their patient population. Such scoring systems may serve as useful bedside nursing tools facilitating awareness of the presence of LCOS and appropriate communication with the medical team. Not all of these scoring systems have been validated; therefore, additional study is needed before their widespread implementation.

At hour 18, we found a clinically relevant increase to moderate agreement among nurses, as well as an increase to moderate agreement with the "answer key." At hour 24, however, agreement among nurses and with the "answer key" returned to only fair overall. These findings indicate that agreement among nurses as well as with the "answer key" is not related to time or level of experience. This unpredictability of agreement also emphasizes the need for nursing education on the signs and symptoms of LCOS (tachycardia, oliguria, peripheral perfusion, increasing difference in arterial versus mixed venous oxygen saturation, and metabolic acidosis).

Limitations

This was a prospective, observational, one-time survey conducted at a single center. The survey involved a small number of participants, particularly in the highest experience category. Because participation was voluntary, a potential sampling bias exists, making it difficult to generalize the results to other intensive care unit nurses. Invasive measures to objectively determine the presence of LCOS were not available. Also, the challenge of determining the clinical status of a patient without an in-person bedside examination—given limited clinical information, laboratory test results, and vital signs—coupled with the absence of a diagnostic gold standard for LCOS constitutes a major limitation of our study. Future research might include expanding the study to other institutions via the Pediatric Cardiac Intensive Care Society network of nurses and physicians to determine whether the results are generalizable.

Conclusion

Our study shows that, regardless of level of experience, nurses have difficulty agreeing among themselves as well as with an "answer key" in the determination of LCOS. This lack of concordance leaves less experienced nurses, who often rely on the leadership of their more experienced counterparts, without clear guidance. Given that pediatric cardiac critical care is a highly specialized, high-risk patient care environment, implementation of an LCOS scoring system might be the best method of increasing nursing bedside recognition of symptoms, facilitating communication with the medical team, and subsequently improving patient outcomes. CCN

Financial Disclosures
None reported.

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