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ORIGINAL ARTICLE

Predictors of Prolonged Length of Intensive Care Unit Stay After Stage I Palliation: A Report from the National Pediatric Cardiology Quality Improvement Collaborative

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Abstract The objective of this study is to identify predictors of prolonged intensive care unit (ICU) length of stay (LOS) for single ventricle patients following Stage I palliation. We hypothesize that peri-operative factors contribute to prolonged ICU stay among children with hypoplastic left heart syndrome (HLHS) and its variants. In 2008, as a part of the Joint Council on Congenital Heart Disease initiative, the National Pediatric Cardiology-Quality Improvement Collaborative established a data registry for patients with HLHS and its variants undergoing staged palliation. Between July 2008 and August 2011, 33 sites across the United States submitted discharge data essential to this analysis. Data describing the patients, their procedures, and their hospital experience were entered. LOS estimates were generated. Prolonged LOS in the ICU was defined as stay greater than or equal to 26 days (i.e., 75th percentile). Statistical analyses were carried out to identify pre-operative, operative, and post-operative predictors of prolonged LOS in the ICU. The number of patients with complete discharge data was 303, and these subjects were included in the analysis. Univariate and multivariate analyses were performed. Multivariate analysis revealed that lower number of enrolled participants (e.g., 1–10) per site, the presence of pre-operative acidosis, increased circulatory arrest time, the occurrence of a central line infection, and the development of respiratory insufficiency requiring re-intubation were associated with prolonged LOS in the ICU. Prolonged LOS in the ICU following Stage I palliation in patients with HLHS and HLHS variant anatomy is associated with site enrollment, circulatory arrest time, pre-operative acidosis, and some post-operative complications, including central line infection and re-intubation. Further study of these associations may reveal strategies for reducing LOS in the ICU following the Norwood and Norwood-variant surgeries.

This study was conducted for the Joint Council on Congenital Heart Disease National Pediatric Cardiology Quality Improvement Collaborative (NPC-QIC).

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Introduction

Hypoplastic left heart syndrome (HLHS) is a particularly lethal form of complex congenital heart disease when left untreated. The most common palliative approach to HLHS involves the performance of three-staged operations. The highest mortality occurs around the time of the first surgery or stage I procedure. The period between the first and second surgeries, referred to as the "interstage period," is also associated with significant risk of mortality. Recent estimates for interstage mortality are 10–15 % [1, 4, 7, 10–12, 14, 17, 24, 25, 27]. Previous studies have identified risk factors associated with mortality after stage I palliation [11, 12, 14, 15, 17, 23, 25, 27]. The objective of this study was to identify factors leading to increased length of stay (LOS) within the intensive care unit (ICU) after stage I palliation [13, 23, 30].

Increased LOS in the ICU after pediatric cardiac surgery has been associated with increased risk of major infection [28], increased financial burden [8, 29], and poorer neurocognitive outcome [19]. Major infections occurring in the ICU may be due to prolonged intubation, development of iatrogenic pneumonias, development of tracheitis, development of other types of drug-resistant microbial infections, and presence of central line infection. Regardless, infection after cardiac surgery is a negative outcome that delays patient recovery, delays patient rehabilitation, adds to patient and familial stress after surgery, and decreases overall quality of life [18].

An earlier study, focusing on the cost associated with the treatment of congenital heart disease (CHD), found that prolonged stay in the ICU was associated with greater hospital-related cost. This study found that prolonged stay in the ICU represented an added financial burden for families. This same study found that decreasing the number of nights a child remained in the hospital after surgery was associated with an average savings of $493/night [29]. A retrospective, observational study of inpatient costs associated with surgical repair of HLHS found that LOS was associated with increased inpatient resource use and cost [8]. Finally, regarding the impact of prolonged LOS in the ICU after pediatric cardiac surgery, more recent studies have shown that increased LOS in the ICU after cardiac surgery, is associated with poorer cognitive function at 8 years of age. In particular, children who remain in the ICU for prolonged periods have a lower full-scale IQ, lower verbal IQ, and tendencies toward lower performance IQ regardless of socio-demographic factors [19].

In 2003, the Joint Council on Congenital Heart Disease (JCCHD) was developed as a leadership alliance to enhance communication across organizations focused on the care of patients with CHD [16]. In 2006, the JCCHD launched the National Pediatric Cardiology-Quality Improvement Collaborative (NPC-QIC) in response to a request by the American Board of Pediatrics and in response to a recognized need for a multi-institutional improvement effort to benefit at-risk patients. The NPC-QIC now includes >50 sites across the United States. The goals of this initiative are to (1) decrease mortality, (2) decrease morbidity, and (3) improve the quality of life of infants with HLHS and its variants.

The purpose of this report is to identify perioperative and operative factors associated with prolonged LOS in the ICU after stage I palliation. Perioperative and operative factors of interest include the following: patient characteristics, type of surgery performed, intraoperative variables, ICU management before surgery, and postoperative management selections.

Materials and Methods

NPC-QIC registry data were collected and stored in a centralized and secured electronic database (Research Electronic Data Capture, Nashville, TN). Participants were admitted to the ICU between June 20, 2008 and August 18, 2011. Each participant contributed data on >200 individual variables. Data were submitted to the registry by the site performing the stage I palliative surgery. Data were then deidentified as to patient name and participating site. The data were routinely audited to ensure completeness.

To be included in the NPC–QIC data registry, subjects were required to satisfy three conditions. First, the patient must have been diagnosed with HLHS or another complex form of CHD requiring the Norwood or Norwood-variant surgery [i.e., Norwood with Blalock–Taussig (BT) shunt, Norwood with right ventricle-to-pulmonary artery conduit, Damus–Kaye–Stansel (DKS) anastomosis with shunt, or hybrid procedure]. Second, the patient must have survived the palliative surgical or hybrid procedure. Third, the patient must have been discharged to home after stage I palliation and before stage II palliation (i.e., bidirectional Glenn surgery). To be included in this report, a date of discharge after stage I palliation was required.

LOS in the ICU was calculated as the time between surgery and final discharge from the ICU. If a subject required multiple admissions to the ICU before being discharged home, the date of final ICU discharge was used to determine total length of ICU stay. In the event that the final date of discharge was missing, the initial discharge date was used. Prolonged LOS in the ICU was defined as a stay ≥26 days (i.e., 75th percentile).

Univariate and multivariate analyses were performed to identify potential predictors of prolonged LOS in the ICU.

All statistical analyses were performed using SAS 9.2 (SAS, Cary, NC). Univariate analyses of categorical variables were performed using χ^2 and Fisher's exact tests. For continuously scaled variables that lacked normal distributions, data were described using quartiles and nonparametric analyses. Logistic regression was used to identify potential predictors of prolonged LOS in the ICU by multivariate analysis.

The NPC-QIC database records the following: individual demographic variables (e.g., sex, race, etc.), individual preoperative factors (e.g., prenatal diagnosis, presence of a genetic syndrome, etc.), individual operative factors (i.e., circulatory arrest time, etc.), and individual postoperative factors (i.e., milrinone use, cardiac arrest, pericardial effusion requiring drainage, etc.). However, the database also includes variables that describe larger categories of events, such as the presence of any preoperative risk factor or the presence of any postoperative complication. These composite variables, describing large categories of events, were first applied in univariate and multivariate analyses. However, specific variables were also screened by univariate analysis. For the multivariate analyses performed, if a composite variable (e.g., any postoperative complication) was found to be significant, the composite variable was removed from the model, and each individual variable within that particular category (e.g., cardiac arrest) was added. A forward-selection method was employed to select variables that were significant predictors of prolonged LOS in the ICU by multivariate analysis.

In addition to the study of composite variables already entered into the NPC–QIC data registry, we created and tested two new composite variables. One of these variables was a composite vasoactive score, and the other was a categorical variable reflecting the number of participants contributed by a particular site. The composite vasoactive score described the number of vasoactive agents administered to a participant during the interstage. The highest allowable score was 6, whereas the lowest was 0. Vasoactive agents included in this score were milrinone, epinephrine, dopamine, norepinephrine, dobutamine, and nipride. The categorical variable reflecting the number of participants contributed by a particular site included the following groups: 1–10 participants, 11–20 participants, and ≥21 participants.

Results

LOS was defined as the time from date of Norwood or Norwood-variant surgery to the date of final discharge. The median LOS was 14 days (IQR 9, 26). For the purpose of our analysis, prolonged LOS in the ICU was defined as LOS ≥26 days (i.e., 75th percentile). Seventy-six participants had LOS ≥26 days.

There were 409 participants in the registry at the time of this study. Three participants were excluded due to missing surgical dates, and 3 participants were excluded due to recorded surgical dates that preceded the recorded date of birth. Approximately one quarter of patients did not have recorded ICU initial or final discharge dates ($N = 97$) and were excluded. Three additional participants had incorrectly entered discharge dates (i.e., ICU discharge dates that preceded the Norwood surgical date) and were excluded. Of the remaining 303 patients, 58 had recorded initial ICU discharge dates that differed from the final ICU discharge date. The final discharge dates, on average, occurred 15 days after the initial discharge date [i.e., mean 15 days (SD = 14)] and may have represented dates of discharge after a readmission to the ICU. Despite the large number of participants with initial and final discharge dates that differed, exclusion of patients with different discharge dates did not result in a significant change in the calculated median LOS (data not shown). The median LOS in the ICU was 13 days (interquartile range [IQR] 8, 21) when these patients were excluded.

Of the 303 participants studied, there were 194 males and 109 females (Table 1). The median age at the time of stage I palliation was 6 days (IQR 4, 8). Participants were most commonly white (72 %) and had a primary diagnosis of HLHS (72 %). There were 33 (11 %) patients diagnosed with a genetic syndrome, and 40 (13 %) patients were diagnosed with a major noncardiac anomaly. Preoperative diagnosis of a genetic syndrome was not associated with prolonged LOS in the ICU ($p = 0.31$). However, diagnosis of a major noncardiac anomaly (e.g., musculoskeletal anomaly) was associated with prolonged LOS ($p = 0.003$).

Race was associated with prolonged LOS in the ICU by univariate analysis. Non-Hispanic white children were less likely to have a prolonged LOS ($p = 0.031$) after stage I palliation with a median duration of 13 days (IQR 8, 22), whereas black and "other" children had significantly longer LOS (Table 1). Race was not a significant predictor by multivariate analysis.

Site characteristics also influenced LOS. For sites enrolling fewer than 10 participants, the median LOS was 17 versus 13 days for sites enrolling ≥21 participants ($p = 0.0047$) (Fig. 1).

Of the 303 patients studied, 175 had an identified preoperative risk factor. The more common preoperative risk factors included the following: preoperative acidosis ($N = 56$), preoperative ventilatory support ($N = 115$), restrictive atrial septum ($N = 56$), and increased serum creatinine ($N = 28$). Univariate analysis showed that only the presence of preoperative acidosis ($p = 0.011$) and preoperative ventilatory support ($p < 0.0001$) were associated with prolonged LOS in the ICU after stage I palliation (Fig. 2).

Table 1 Demographic, preoperative, operative, and postoperative variables

Factor	Sex	*N*	Median (IQR) ICU LOS (days)	*p* Value
Demographic data				
Sex	Male	194	14 (9, 24)	0.98
	Female	109	13 (9, 26)	
Race	White	218	13 (8, 22)	0.031
	Black	48	16.5 (11, 30.5)	
	Other	37	20 (10, 28)	
Primary diagnosis	HLHS	218	13 (8, 26)	0.69
	Other	85	15 (9, 25)	
Prenatal diagnosis	Yes	227	14 (9, 26)	0.74
	No	76	14.5 (8, 22)	
Genetic syndrome	Yes	33	17 (9, 25)	0.31
	No	270	13 (8, 26)	
Major (noncardiac) anomaly	Yes	40	21.5 (12.5, 30)	0.003
	No	263	13 (8, 24)	
Preoperative data				
Risk factor (all)	Yes	175	17 (10, 28)	0.004
	No	128	12 (8, 20.5)	
Preoperative acidosis	Yes	56	19.5 (11, 32.5)	0.011
	No	247	13 (8, 24)	
Preoperative ventilatory support	Yes	115	19 (11, 30)	<0.0001
	No	188	12 (8, 21)	
Restrictive atrial septum	Yes	56	14 (10.5, 25.5)	0.45
	No	247	14 (8,26)	
Moderate/severe depressed ventricular function	Yes	9	15 (12, 20)	0.96
	No	294	14 (9, 26)	
Moderate/severe atrioventricular valve regurgitation	Yes	12	13 (11, 17.5)	0.83
	No	291	14 (9, 26)	
Operative data				
Procedure performed				
Norwood/BT Shunt		92	16.5 (9, 33)	0.24
Norwood/Sano		169	14 (9, 25)	
DKS/Shunt		13	13 (9, 22)	
Hydrid		28	11 (7.5, 22.5)	
Postoperative complications and management				
Any postoperative complication	Yes	197	19 (11, 30)	0.0001
	No	106	10 (7, 13)	
Cardiac arrest	Yes	14	28 (14, 42)	0.0022
	No	289	13 (8, 24)	
Mechanical circulatory support	Yes	13	43 (30, 83)	<0.0001
	No	290	13 (8, 24)	
Any reoperation	Yes	53	24 (14, 41)	<0.0001
	No	248	13 (8, 22)	
RV-to-PA conduit revision	Yes	3	37 (30, 41)	0.02
	No	166	13 (8,24)	
BT shunt revision	Yes	5	42 (39, 57)	0.03
	No	87	15 (9, 27)	
Greater than 1 ICU admission	Yes	61	24 (13, 37)	0.0001
	No	241	13 (8, 21)	

Table 1 continued

Factor	Sex	*N*	Median (IQR) ICU LOS (days)	*p* Value
Atrioventricular block, temporary pacing	Yes	6	36.5 (19, 48)	0.0097
	No	297	14 (9, 25)	
Arrhythmia	Yes	43	21 (12, 36)	0.0017
	No	260	13 (8, 24)	
Pericardial effusion requiring drain	Yes	5	26 (17, 68)	0.045
	No	298	14 (9, 25)	
Respiratory insufficiency requiring vent support >14 days	Yes	31	32 (24, 71)	<0.0001
	No	272	13 (8, 21.5)	
Respiratory insufficiency requiring reintubation	Yes	38	38 (26, 58)	<0.0001
	No	265	13 (8, 21)	
Pleural effusion requiring drainage	Yes	24	26 (21, 40.5)	<0.0001
	No	279	13 (8, 24)	
Postoperative bleeding requiring reoperation	Yes	12	21.5 (14, 42.5)	0.03
	No	291	13 (8, 25)	
Endocarditis	Yes	3	31 (28, 61)	0.03
	No	300	14 (9, 25)	
Septicemia	Yes	19	27 (20, 83)	<0.0001
	No	284	13 (8, 24)	
Central line infection	Yes	17	35 (20, 45)	<0.0001
	No	286	13 (8, 24)	
Seizure	Yes	10	26.5 (17, 43)	0.0059
	No	293	13 (8, 25)	
NEC	Yes	11	26 (14, 61)	0.0062
	No	292	13.5 (8, 25)	
Medications				
Calcium	Yes	76	18 (11.5, 30)	0.0034
	No	227	13 (8, 24)	
Dobutamine	Yes	35	18 (11, 37)	0.024
	No	268	13 (8, 24)	
Dopamine	Yes	172	13.5 (8, 25)	0.5
	No	131	14 (9, 26)	
Epinephrine	Yes	204	16 (10, 28)	0.0013
	No	99	11 (8, 20)	
Milrinone	Yes	271	14 (9, 26)	0.15
	No	32	12 (9, 21.5)	
Nipride	Yes	37	18 (11, 29)	0.24
	No	266	13 (9, 25)	
Norepinephrine	Yes	5	23 (19, 27)	0.27
	No	298	14 (9, 25)	
Vasopressin	Yes	32	22 (9, 39)	0.06
	No	271	13 (9, 24)	

Univariate analysis

Patients underwent either Norwood or Norwood-variant surgery. Ninety-two patients (30 %) underwent Norwood/BT shunt, 169 (56 %) underwent Norwood/Sano shunt, 13 (4 %) underwent DKS/shunt, and 28 (9 %) underwent a hybrid procedure. There was no statistically significant trend toward Norwood BT/shunt recipients experiencing prolonged LOS in the ICU ($p = 0.22$) although patients who underwent Norwood/BT shunt surgery remained in the ICU for 2.5 days longer than patients who underwent Norwood/Sano surgery ($p = 0.24$) (Table 1).

Operative factors (data not shown) also contributed to prolonged LOS in the ICU. Subjects who underwent a

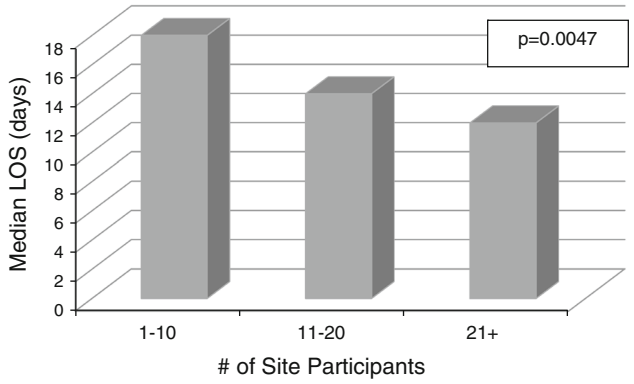

Fig. 1 Median ICU LOS (median LOS) by the number of enrolled NPC-QIC participants (no. of site participants). Sites were divided by the number of participants enrolled during July 2008 and August 2011. Site participation was arbitrarily divided into the following groups: 1–10 participants, 11–20 participants, and ≥21 participants. Median LOS is reported for each group. There is a statistically significant trend toward fewer median days in the ICU after stage I palliation as the number of participants increases ($p = 0.0047$)

nonhydrid procedure had a median cardiopulmonary bypass time of 144 minutes (IQR 113, 173), median circulatory arrest time of 8.7 minutes (IQR 1, 35), and median aortic cross-clamp time of 55 minutes (IQR 41, 75). Longer circulatory arrest time was associated with longer ICU stay ($p = 0.02$) (Table 2) such that 10 minutes of circulatory arrest time was associated with 20 % greater odds of prolonged LOS.

The development of a postoperative complication was reported for 197 patients (65 %) and was significantly associated with prolonged LOS in the ICU ($p = 0.0001$) (Table 1). Univariate analyses showed many, but not all, post-operative complications to be associated with prolonged LOS. Of the recorded postoperative complications,

Table 2 Multivariate analysis: Predictors of prolonged LOS in the ICU after stage I palliation

Factor	Odds ratio for prolonged LOS in the ICU	Confidence interval	*p* Value
Site participant number			
11–20 participants (vs. 1–10)	0.54	0.21–1.4	0.94
21+ participants (vs. 1–10)	0.27	0.12–0.60	0.0092
Pre-operative acidosis	3.1	1.4–6.8	0.0039
Circulatory arrest (/min)	1.02	1.005–1.04	0.0082
More than 1 ICU admission	4.6	2.1–10.0	0.0001
Postoperative central line infection	8.3	2.3–30.4	0.0015
Respiratory insufficiency requiring reintubation	17	6.0–48	<0.0001

Predictors of prolonged LOS in the ICU by multivariate analysis. Data reflects logistic regression results. The odds ratios for prolonged LOS in the ICU (i.e., ≥26 days) are reported. Multivariate analyses suggest that the odds of remaining in the ICU for ≥26 days is lower as the number of participants per site increases. However, increasing circulatory arrest time, presence of preoperative acidosis, development of a postoperative central line infection, and respiratory insufficiency requiring reintubation were associated with prolonged LOS in the ICU

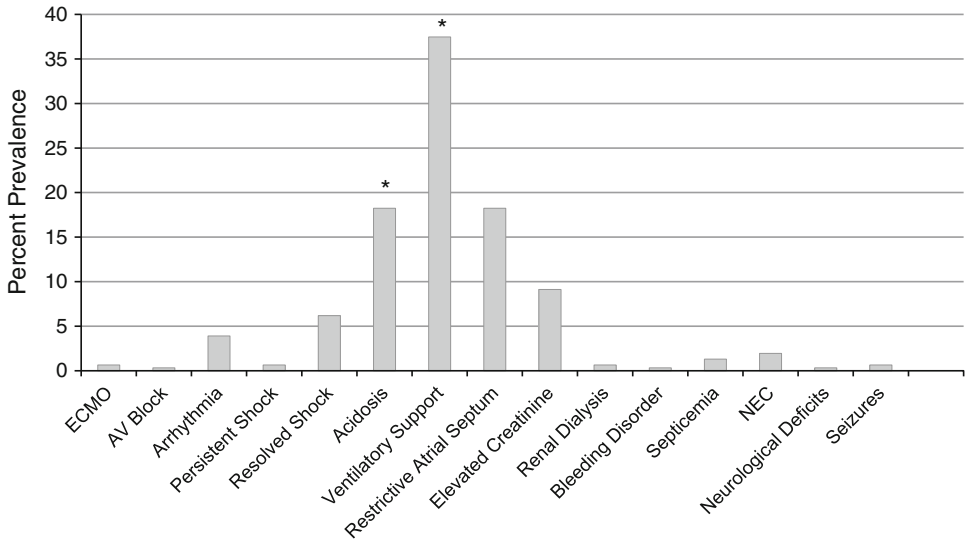

Fig. 2 Prevalence of preoperative risk factors. Among the 303 participants in this study, there were a total of 307 reported preoperative risk factors. The prevalence of each risk factor is reported as a percent of the total number of reported preoperative risk factors. Two of the preoperative risk factors were associated with prolonged LOS in the ICU. In particular, preoperative acidosis and preoperative ventilatory support were significantly associated with prolonged LOS by univariate analysis (*$p < 0.05$). However, only the presence of preoperative acidosis was associated with prolonged LOS in the ICU by multivariate analysis. Variables: *ECMO* extracorporeal membrane oxygenation, *AV block* atrioventricular block, *NEC* necrotizing enterocolitis

arrhythmia, respiratory insufficiency requiring reintubation or prolonged ventilatory support, effusions requiring drainage, infections, cardiac arrest, circulatory arrest requiring mechanical support, reoperation, necrotizing enterocolitis, seizures, atrioventricular block requiring pacing, and endocarditis were associated with prolonged LOS in the ICU by univariate analysis (Fig. 3).

Examination of the relationship between inotropic-agent use and prolonged LOS in the ICU showed that the number of agents used was directly related to a greater likelihood of remaining in the ICU for ≥26 days (Fig. 4). Individuals who received five or more vasoactive agents remained in the ICU for ≥26 days 100 % of the time, whereas those who received only one vasoactive agent remained in the ICU for ≥26 days only 10 % of the time.

Finally, a logistic regression model was constructed to identify individual variables associated with prolonged LOS in the ICU. The strongest predictors of prolonged LOS in the ICU were the development of a postoperative central line infection and respiratory insufficiency requiring reintubation. Other significant predictors of prolonged LOS in the ICU by multivariate analysis included the number of participants contributed by a particular site, circulatory arrest time, and the presence of preoperative acidosis. All other variables identified by univariate analysis were not significant predictors of prolonged LOS in

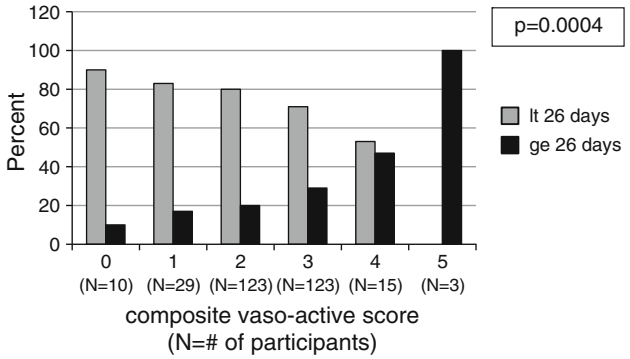

Fig. 4 Percent of participants remaining in the ICU for ≥26 days *versus* number of vasoactive agents (composite vasoactive score) used during the interstage period. A composite vasoactive score was generated and included the number of vasoactive agents administered to an individual participant during the interstage period. The percentage of participants with LOS <26 days (lt 26 days) versus LOS ≥26 days (ge 26 days) was determined. Overall, the trend suggests that there was a greater likelihood of prolonged ICU stay with each additional use of a vasoactive agent

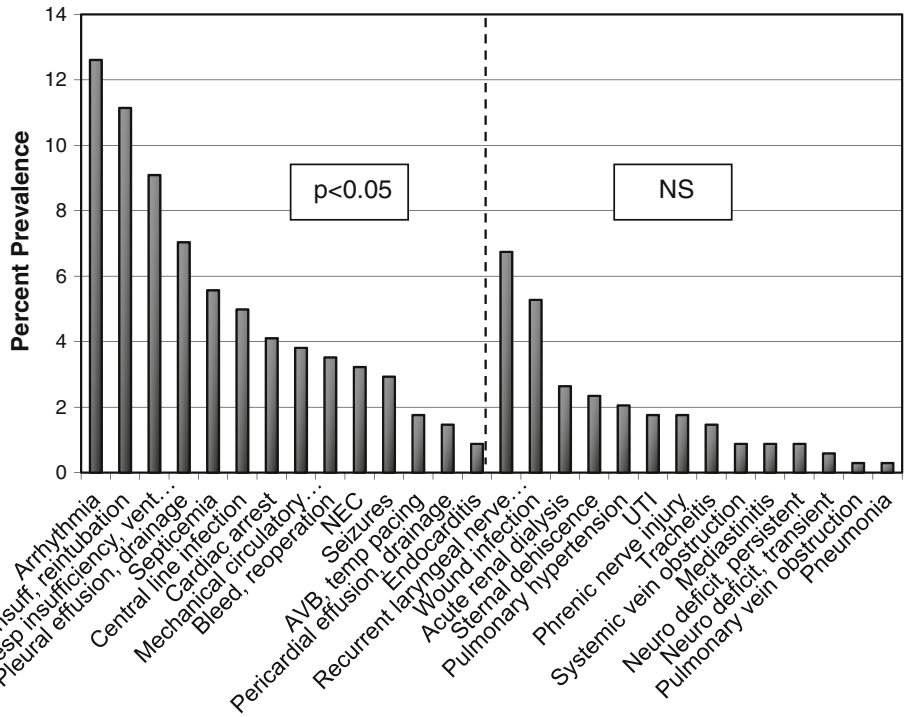

Fig. 3 Prevalence of postoperative complications. There were a total of 341 reported postoperative complications. Postoperative complications significantly associated with prolonged LOS in the ICU by univariate analysis are listed along the left side of the graph. Variables: *Resp insuff, reintubation,* respiratory insufficiency requiring reintubation; *Resp insuff, vent,* respiratory insufficiency requiring ventilator support > 14 days; *Mechanical circ...*, mechanical circulatory support; *Bleed, reoperation*, bleed requiring reoperation; *NEC*, necrotizing enterocolitis; *AVB, temp pacing,* atrioventricular block requiring temporary pacing; *Pericardial effusion, drainage,* pericardial effusion requiring drainage; *Recurrent laryngeal nerve...,* recurrent laryngeal nerve injury; *UTI,* urinary tract infection; *Neuro deficit, persistent,* persistent neurologic deficit; *Neuro deficit, transient,* transient neurologic deficit. Only respiratory insufficiency requiring reintubation and central line infection were associated with prolonged LOS in the ICU by multivariate analysis (*NS,* nonsignificant)

the ICU after Norwood or Norwood-variant procedure by multivariate analysis.

Discussion

This work represents one of few multi-institutional studies to describe factors associated with prolonged ICU stay after stage I palliation [23]. It is clear, based on single-center studies and observational studies using administrative databases, that prolonged ICU stay after cardiac surgery is associated with increased morbidity, including increased infection risk, increased cost, and poorer long-term neurocognitive outcome [8, 13, 19, 28–30].

Our results, similar to previously published data, suggest that prolonged ICU stay after stage I palliation is associated with preoperative, operative, and postoperative factors, including ones that may reflect differences in practice that are not patient-driven [3, 5, 6, 13, 21, 22, 26, 30]. The challenge in interpreting many of these associations lies in discerning the impact of the factor (e.g., reintubation) from the impact of the reason for that factor (e.g., congenital airway anomaly).

Several of the factors associated with prolonged LOS in the ICU, by univariate analysis, cannot be modified. These nonmodifiable risk factors include the following: patient features, such as the presence of a major noncardiac anomaly (e.g., musculoskeletal anomaly) and some demographic parameters (e.g., race).

Race (e.g., white, black, other) was associated with prolonged LOS by univariate analysis. We are not the first to report worse outcomes for nonwhite patients undergoing stage I palliation [9]. Potential causes of poorer outcome among nonwhite participants include lower birth weight and delayed surgery. Previous studies have shown that nonwhite patients have lower weight for age z-scores [2]. Similarly, we found that black participants had significantly lower birth weights compared with white and "other"-race participants [median birth weight of 3 kg (IQR 2.7, 3.3)] for black participants versus median birth weight of 3.2 kg (IQR 2.92, 3.5) for white participants and 3.2 kg (IQR 2.86, 3.5) for "other"-race participants].

The timing of stage I palliation may be delayed among nonwhite participants. In a recently published study, nonwhite patients were more likely to be admitted from home at the time of their stage I palliation [9]. However, we did not find that age at time of ICU admission was significantly greater among nonwhite versus white participants. In fact, the median age at time of ICU admission was 0 days for all participants.

Although nonmodifiable risk factors and demographic parameters were found to be significant predictors of prolonged LOS by univariate analysis, when these factors were considered in a multivariate model, they were not significant predictors of prolonged LOS in the ICU. In fact, nonmodifiable risk factors and demographic parameters were not associated with prolonged LOS when we considered other factors, such the number of participants enrolled by site or the number of inotropic agents used.

Modifiable risk factors—such as the number of participants enrolled by site (i.e., 1–10 vs. $\geq$21 participants), duration of circulatory arrest time, and presence of preoperative acidosis—were associated with prolonged LOS in the ICU. It is noteworthy that the number of participants enrolled by site is a significant predictor of prolonged LOS in the ICU. This finding, a modifiable risk factor, may support the notion that center experience plays a significant role in determining how long a particular patient remains in the ICU. However, this variable may also be a marker of inadequate resources at smaller centers (e.g., absence of a step-down unit for patients who are less critically ill) or the inability to treat and manage more complex issues outside of the ICU.

Preoperative acidosis may be a modifiable risk factor for prolonged ICU stay. Preoperative acidosis may be a reflection of preoperative management, secondary to pulmonary over circulation in the setting of compromised systemic perfusion (i.e., increased QP to QS) or a reflection of clinical severity. Nevertheless, better control of preoperative acidosis is achievable in many cases and, if managed appropriately, improvement in the preoperative acid–base balance may represent a means for improving outcome.

Another modifiable risk factor found to be a significant predictor of prolonged LOS in the ICU was circulatory arrest time. For each 10 minutes of circulatory arrest time, the odds of remaining in the ICU increased by 20 %. This is important because circulatory arrest time may reflect surgical approach, but it may also reflect the severity of the condition. Therefore, future studies evaluating the role of circulatory arrest time on LOS are needed.

Finally, several postoperative factors were identified as significant predictors of prolonged LOS in the ICU. Although a combined vasoactive agent score was created, and even though the score was associated with a trend toward longer LOS in the ICU (Fig. 3), this variable was not a significant predictor of prolonged LOS in the ICU according to our final multivariate logistic regression model. Only need for greater than one ICU admission, presence of a central line infection, and development of respiratory insufficiency requiring reintubation were significant independent predictors of prolonged stay.

It is debatable whether need for more than one ICU admission, development of a central line infection, and need for reintubation represent modifiable risk factors for prolonged LOS in the ICU. The need for greater than one

ICU admission intuitively is associated with prolonged stay and need not be argued. However, development of a central line infection and need for reintubation represent potentially modifiable risk factors. Development of a central line infection may be an indication of poor line-placement protocol, poor infection-control procedure, or insufficient experience with the management and care of central lines.

The development of respiratory insufficiency requiring reintubation may occur secondary to a major noncardiac anomaly (e.g., underlying airway abnormality) and represent a nonmodifiable risk factor. However, development of respiratory insufficiency requiring reintubation is more likely to represent the approach to intubation or postoperative care. Changes in the postoperative respiratory management of children with HLHS may lead to fewer episodes of respiratory compromise and better outcomes.

Registry data such as these cannot be used to determine the basis or appropriateness of the medical decisions, which might be modifiable, but they are useful for two reasons. First, as best practices are sought, many of the associations between modifiable factors and prolonged LOS in the ICU may be explored through more powerful randomized clinical trials designed specifically for that purpose. In addition, as providers contemplate the complex clinical choices required to help infants with HLHS survive, new approaches that eliminate even potential unwanted effects may emerge.

Limitations

During the Norwood hospitalization admission, ICU admission and discharge data were generally robust for patients with a single ICU admission. For patients with multiple ICU admissions, transfer data were not recorded (i.e., dates of readmission to the ICU were not recorded), leading to imprecision in our measurement of LOS for this subgroup. Next, because only patients discharged to home before stage II surgery were included, we have no information regarding patients who remained hospitalized throughout the interstage period. This could conceivably introduce a bias into our understanding of "risk factors" for prolonged LOS. Rather than increasing the risk of prolonged LOS in the ICU, a factor could even be protective of the need for hospitalization throughout the interstage period (Neyman bias) [20]. Based on the data available, we were unable to evaluate whether such biases influenced our findings. A third limitation of our study is that enrollment number may have reflected when a particular site joined the NPC–QIC versus the site's experience caring for HLHS and HLHS-variant patients. A final limitation of our study was our inability to characterize indications and explanations for particular preoperative, operative, and postoperative management decisions. For example, it is possible that particular centers are more likely to use multiple vasoactive agents initially but then wean the agents quickly. It is also possible that use of particular vasoactive agents is reflective of worsening patient clinical status.

Despite the limitations of our study, the results of this study provide insight into the potential role of modifiable factors on length of ICU stay after stage I palliation for HLHS. It suggests that variations in practice can contribute to prolonged LOS in the ICU. It also suggests that further studies are needed.

Conclusion

Prolonged LOS in the ICU after stage I palliation is associated with site participant number and with variation in preoperative, operative, and postoperative management. Number of participants per site, presence of preoperative acidosis, longer circulatory arrest time, need for more than one ICU admission, acquisition of a central line infection, and development of respiratory insufficiency requiring reintubation were all associated with prolonged LOS in the ICU after stage I palliation. Further studies will be needed to discern whether these associations are causal and whether changes in practice can improve patient outcomes by decreasing the morbidity of prolonged stay in the ICU.

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