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ORIGINAL ARTICLE

Predictors of Prolonged Hospital Length of Stay Following Stage II Palliation of Hypoplastic Left Heart Syndrome (and Variants): Analysis of the National Pediatric Cardiology Quality Improvement Collaborative (NPC-QIC) Database

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Abstract The objective of this study is to identify predictors of prolonged hospital length of stay (LOS) for single ventricle patients following stage 2 palliation (S2P), excluding patients who underwent a hybrid procedure. We explore the impact of demographic features, stage 1 palliation (S1P), interstage I (IS1) management, S2P, and post-surgical care on hospital LOS following S2P. We conducted a retrospective analysis of the National Pediatric Cardiology Quality Improvement Collaborative (NPC-QIC) database. The NPC-QIC database is an established registry of patients with hypoplastic left heart syndrome (HLHS) and its variants. It contains detailed information regarding the demographic features, S1P, IS1, S2P, and interstage 2 (IS2) management of children with HLHS and related single ventricle cardiac malformations. Between 2008 and 2012, there were 477 participants with recorded LOS data in the NPC-QIC registry. Excluding the 29 patients who underwent hybrid procedure, there were 448 participants who underwent a Norwood (or Norwood-variant procedure) as S1P. In order to be included in the NPC-QIC database, participants were discharged to home following S1P and prior to S2P. We found that postoperative LOS among the 448 S2P procedure recipients is most strongly influenced by the need for reoperation following S2P, the need for an additional cardiac catheterization procedure following S2P, the use of non-oral methods of nutrition (e.g., nasogastric tube, total parental nutrition, gastrostomy tube), and the development of postoperative complications. Factors such as age at the time of S2P, the presence of a major non-cardiac anomaly, site participant volume, IS1 course, the type and number of vasoactive agents used following S2P, and the need for more than 1 intensive care unit (ICU) hospitalization (following discharge to the ward but prior to discharge to home) were significant predictors by univariate analysis but not by multivariate analysis. We excluded participants undergoing the hybrid procedure as S1P from this analysis given that the S2P following the initial hybrid is typically a more complicated procedure. Hospital LOS following S2P among children undergoing the Norwood or Norwood-variant procedure as S1P is most strongly influenced by events following S2P and not demographic or S1P factors. Factors most predictive of prolonged LOS include the need for reoperation, the need for an additional cardiac catheterization procedure following S2P, the need for non-oral methods of nutrition, and the development of postoperative complications.

Keywords Hypoplastic left heart syndrome · Bidirectional Glenn procedure · Hospitalization · Length of stay

Introduction

Approximately 0.8 % of infants are born with congenital heart disease, and of those, 1.25 % are born with univentricular heart defects [29]. Currently, accepted practice management for single ventricle patients is a three-stage palliative surgical approach. The first stage includes the

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Norwood procedure (i.e., stage 1 procedure). The goal of the stage 1 procedure (S1P) is to provide a reliable source of pulmonary blood flow while ensuring adequate systemic perfusion. Options for S1P include Norwood with a modified Blalock–Taussig shunt (mBTS) or Norwood with a right ventricle to pulmonary artery conduit (RV-PA conduit). The hybrid procedure is another option for S1P [5, 13]. The hybrid procedure includes initial balloon atrial septostomy, stenting of the ductus arteriosus, and placement of bilateral branch pulmonary artery (PA) bands. Unlike for those undergoing the Norwood (or Norwood-variant) approach, the major surgical stage is shifted to the time of the S2P among those undergoing the hybrid procedure and is thus a more complicated stage 2 palliation (S2P) [13].

S2P, also known as the superior cavopulmonary anastomosis, was first introduced in the 1980s [12]. Compared to the period following the S1P, the period following the S2P is considered a more stable time and has been associated with a lower interstage mortality [12, 21]. S2P has become the next step and standard of care in the management of single ventricle patients [7, 23, 28]. It is typically performed between 4 and 6 months of age. However, at some centers, the S2P is performed as early as 2 months of age [16]. There are two types of S2P procedures: the bidirectional Glenn procedure (BDG) and the hemi-Fontan procedure (HFP). Both procedures involve takedown of the RV to PA conduit or BT shunt and (typically) the use of cardiopulmonary bypass (CPB). The BDG involves division of the superior vena cava (SVC) from the right atrium and anastomosis of the SVC to the pulmonary arteries. The HFP involves creation of an aortopulmonary anastomosis without division of the SVC via placement of an intra-atrial patch [11].

Although the interstage period following S2P is felt to be a lower risk period, complications still arise. Knowledge of risk factors associated with prolonged stay following S2P is important for identification of patients at greatest risk of poor outcome, for improving cost, and for improving resource utilization following the S2P. To date, the majority of studies have focused on demographic factors that influence outcome following S2P [4, 24, 27].

One benefit of examining the NPC-QIC data registry is that we are able to analyze not only demographic and surgical factors, but also outpatient management strategies, procedures, and complications taking place during the first interstage (IS1). Given that IS1 is a time for optimizing a child's health and ensuring that a child is the best suitable S2P candidate, we consider the impact of management during IS1 on LOS following S2P.

The importance of identifying factors contributing to prolonged LOS following S2P cannot be overemphasized. Efforts to reduce hospital cost and resource utilization continue. Identification of risk factors associated with increased LOS following the S2P procedure may lead to decreased morbidity, reduced cost, and improved resource allocation [6].

Methods

The National Pediatric Cardiology Quality Improvement Collaborative (NPC-QIC) was established by the Joint Council on Congenital Heart Disease in 2006. The NPC-QIC registry is an extensive database. As of November 2012, there were 542 HLHS and related single ventricle patients from 44 participating medical centers throughout the USA in the database. It includes demographic data, interstage and procedural data for participants undergoing S1P and who were discharged to home prior to S2P [18]. The database also contains information about the S2P and postoperative course following S2P (i.e., during IS2). Data in the NPC-QIC registry are collected by participating centers and then uploaded to a secured Research Electronic Data Capture (REDCAP) (Nashville TN) center. To be included in the registry, subjects satisfied three conditions: (1) diagnosis of HLHS or another complex form of congenital heart disease requiring Norwood or Norwood-variant surgery, (2) survival of the S1P surgical or hybrid procedure, and (3) discharge to home after S1P and before S2P. To be included in our analysis, the participant had to have a recorded date of S2P and a recorded date of discharge following S2P.

Univariate and multivariate analyses were performed to identify potential predictors of prolonged LOS following the S2P. All statistical analyses were performed using SAS 9.3 (SAS, Cary, NC). Continuously scaled variables were described using quartiles. Nonparametric analyses were carried out using the Kruskal–Wallis test and the Mann–Whitney U test. Logistic regression was used to identify potential predictors of prolonged LOS following the S2P. Median LOS following the S2P was 8 days. The upper quartile for LOS following S2P was 14 days. As a result, prolonged LOS was defined as hospital LOS greater than 14 days. Significance was considered a p value of > 0.05.

Results

Approximately 477 participants with recorded LOS data were enrolled in the NPC-QIC data registry at the time of data analysis. Of the 477, 448 participants underwent a Norwood (or Norwood-variant) procedure as S1P and were evaluated in this study. Participants were enrolled from 44 sites, between June 17, 2008, and June 26, 2012, and underwent S2P between December 2, 2008, and October 24,

2012. Median hospital LOS was 8 days (IQR 6, 14 days). Median length of stay in the ICU was 4 days (IQR 2, 7).

Demographic Data

The majority of patients underwent S2P procedure between 4 and 6 months of age (57 %) and had a median weight of 6.1 kg at the time of S2P. Most participants were male, white, and of non-Latino descent. A primary diagnosis of HLHS with aortic and mitral atresia was common (36 %). Fewer than 10 % had a major syndrome, and 12 % had a major non-cardiac anomaly. The greatest number of children was enrolled from centers with 20 or more registry participants.

Of the included demographic features, only age at S2P, the presence of a major non-cardiac anomaly and center volume were associated with significant increases in LOS following S2P by univariate analysis. Children who underwent S2P between 2 and 4 months of age had a median LOS 3 days longer than those who underwent S2P during the more traditional age of 4–6 months. The presence of a major non-cardiac anomaly was also associated with increased LOS (11 versus 7 days; $p = 0.001$). Children who were participants from larger enrolling centers tended to have shorter LOS (7 versus 8 days; $p = 0.0008$) (Table 1).

A primary diagnosis of HLHS versus another form of single ventricle was not associated with a significant difference in LOS following S2P (median LOS of 7 versus 8 days, respectively; $p = 0.65$) (data not shown). In addition, a primary diagnosis of aortic atresia versus aortic stenosis was not associated with a significant difference in LOS ($p = 0.33$) (data not shown).

Stage 1 and Interstage 1

Most participants underwent a Norwood with RV to PA conduit (58 %) as S1P. Thirty-seven percent underwent a Norwood with modified BTS, and approximately 5 % of the participants underwent a Damus–Kaye–Stansel (DKS) procedure.

During IS1, most participants were seen fewer than 10 times in the clinic (81 %). There were fairly equivalent numbers of unscheduled and scheduled readmissions (33 % with unscheduled readmission(s) versus 37 % with scheduled readmission(s), $p = 0.06$). Most participants (65 %) did not visit the emergency department during IS1.

Adverse events during IS1 were rare (0.22–2 %) (data not shown). The number of redflag events was not uncommon during IS1 (13 %). Unscheduled cardiac surgery occurred in 11 % of cases and unscheduled cardiac catheterization in 16 %. Home surveillance was common during the IS1 and occurred at least daily (56 %).

Various medications were used during IS1 (data not shown). Lasix ($N = 233$, 52 %) and Digoxin ($N = 98$, 22 %) were the most commonly used agents. Other cardiovascular-related medications used during IS1 included Diuril ($N = 9$, 2 %), spironolactone ($N = 25$, 6 %), Captopril ($N = 74$, 16 %), Enalapril ($N = 76$, 17 %), and Lisinopril ($N = 5$, 1 %). Non-cardiovascular medications used following S1P included aspirin ($N = 35$, 8 %), clopidogrel ($N = 13$, 3 %), and Lovenox ($N = 16$, 4 %).

We analyzed the relationship between S1P, IS1 management, and LOS following S2P. We found that there was no significant difference in LOS following S2P among Norwood BTS versus Norwood/RV to PA conduit and DKS recipients ($p = 0.09$) (Table 2).

We also examined the relationship between management during IS1 and LOS following the S2P. We found that there was no significant difference in LOS following S2P according to the number of clinic visits, unscheduled readmissions, emergency room visits, or reported adverse events. However, a redflag event for a breathing-related concern was associated with greater LOS following S2P (i.e., 13 vs. 7 days; p value $= 0.016$) (Table 2). Similarly, the need to perform an unanticipated procedure, either surgical or catheter based, during IS1, was associated with greater LOS.

Surveillance during IS1 is an important component of the NPC-QIC. Surveillance methods include home monitoring of oxygen saturation and weight or oxygen saturation alone. While the mode of surveillance did not significantly influence LOS following the S2P, frequency did. Daily surveillance was associated with greater LOS than was other frequencies (median LOS 8 vs. 7 days; $p = 0.0014$) (Table 2).

Of the cardiovascular medications used during IS1, only Lasix and spironolactone were associated with significantly increased LOS following S2P. Other cardiovascular medications such as Digoxin, Diuril, Captopril, Enalapril, and Lisinopril were not associated with increased LOS (data not shown). Non-cardiovascular medications used following S1P, including aspirin, clopidogrel, and Lovenox, were also not associated with increased LOS following S2P (data not shown).

Stage 2 and Interstage 2

The majority of participants underwent a unilateral BDG/unilateral HFP (77 %). Oxygen saturations at the time of admission for S2P were predominantly between 75 and 85 %. In addition to undergoing the BDG or HFP, 30 % of participants underwent an additional surgical procedure (e.g., atrial septectomy, aortic arch repair, pulmonary artery angioplasty, or atrioventricular valve repair) at the time of S2P (Table 3).

Table 1 Demographic data, median length of stay (median LOS) in the hospital following stage 2 palliation (S2P)

Length of stay following the bidirectional Glenn procedure (days)	*N*	%	Median LOS	IQR	Range	*p* value
Variable						
Total length of stay following S2P (days)	448		8	5, 14	2, 372	
Duration of ICU stay following S2P (days)	383		4	2, 7	1, 368	
Weight at S2P (kg)	447		6.1	5.5, 6.8	3.4, 10.2	
Age at surgery						
2–4 months	92	20	10	6, 19	2, 141	0.014
4–6 months	256	57	7	5, 14	2, 370	
>6 months	100	22	7	5, 12	3, 372	
Gender						
Male	291	65	8	6, 14	2, 372	0.41
Female	157	35	7	5, 13	2, 118	
*Oxygen saturation at admission for S2P**						
<75 %	92	20	8	6, 17	2, 141	0.88
75–85 %	301	67	8	5, 13	2, 181	
Greater than 85 %	40	9	7	4, 22	3, 372	
Race						
White	322	72	8	5, 16	2, 181	0.56
Black	66	15	7	5, 13	3, 185	
Asian	3	0.67	7	5, 9	5, 9	
Other	57	13	8	6, 14	3, 372	
Ethnicity						
Latino	100	22	8	6, 17	2, 370	0.24
Non-Latino	299	67	7	5 13	2, 181	
Missing	49	11	8	5, 15	4, 372	
Primary diagnosis						
HLHS AA/MA	160	36	8	5, 14	2, 370	0.7
HLHS AA/MS	77	17	8	6, 11	2, 185	
HLHS AS/MA	11	2	8	4, 10	3, 77	
HLHS AS/MS	85	19	8	6, 19	3, 372	
Unbalanced AV canal	18	4	9.5	6, 15	3, 108	
Other single ventricle	97	22	7	5, 11	3, 87	
Major non-cardiac anomaly						
Any	52	12	11	7, 28	3, 370	0.001
None reported	396	88	7	5, 13	2, 372	
Major syndrome						
Any	30	7	9.5	6, 22	3, 87	0.07
None reported	418	93	7	5, 14	2, 372	
Site participant volume						
1–10 participants	122	27	8	6, 18	3, 372	0.0008
11–20 participants	133	30	8	6, 17	3, 118	
21 or more participants	193	43	7	5, 11	2, 370	

* $N = 15$ with missing oxygen saturation at admission for S2P

IS2 management involved the use of various vasoactive agents, including milrinone, epinephrine, dopamine, dobutamine, norepinephrine, calcium, vasopressin, and Nipride. Ninety-six percent received at least one vasoactive agent during IS2, while approximately 9 % received at least three vasoactive agents.

The need for more than 1 ICU hospitalization (defined as more than 1 ICU re-admission from the ward or step-

Table 2 First interstage (IS1), median length of stay (median LOS) in the hospital following stage 2 palliation (S2P)

Interstage data: length of stay following S2P (days)	*N*	%	Median LOS	IQR	Range	*p* Value
Type of stage 1 procedure						
Norwood BTS	165	37	8	6, 15	2, 372	0.09
Norwood/RV to PA conduit	260	58	7	5, 13	2, 181	
DKS/other	23	5	9	5, 14	3, 87	
Clinic visits prior to S2P						
≥10 clinic visits	43	10	7	5, 10	3, 44	0.26
<10 clinic visits	364	81	8	5, 14	2, 372	
Missing	41	9	13	7, 30	4, 185	
Unscheduled readmissions						
Occurred	150	33	7	5, 13	3, 372	0.06
Did not occur	167	37	9	6, 18	2, 185	
Not indicated	131	29	7	5, 11	3, 62	
Number of emergency room visits during interstage						
0	291	65	7	5, 12	2, 141	0.32
1	82	19	9	6, 15	2, 372	
2	22	4.9	7	5, 14	3, 33	
3	9	2.0	8	7, 10	4, 44	
4	2	0.5	15	10, 19	10, 19	
5	1	0.2	8	n/a	n/a	
Not indicated	41	9.2	13	7, 30	4, 185	
Adverse events during IS1						
Cardiac arrest						
None or missing	445	99	8	5, 14	2, 372	0.22
At least one reported event	3	1	18	7, 22	7, 22	
Infection						
None or missing	438	98	8	5, 14	2, 372	0.63
At least one reported infection	10	2	7	6, 9	2, 13	
Number of (total) redflag events reported during IS1						
0 redflag event/missing	391	87	7	5, 13	2, 372	0.19
At least one redflag event	57	13	8	5, 22	3, 118	
Number of redflag events related to breathing during IS1						
0 redflag event/missing	427	95	7	5, 14	2, 372	0.016
At least one redflag event	21	5	13	7, 33	4, 118	
Number of redflag events related to cyanosis						
0 redflag event/missing	423	94	7	5, 14	2, 372	0.08
At least one redflag event	25	6	10	6, 30	3, 82	
Number of redflag events related to diarrhea						
0 redflag event/missing	439	98	8	5, 14	2, 372	0.69
At least one redflag event	9	2	7	6, 19	3, 39	
Number of redflag events related to weight gain						
0 redflag event/missing	433	97	8	5, 14	2, 372	0.16
At least one redflag event	15	3	6	4, 15	3, 56	
Number of redflag events related to vomiting						
0 redflag event/missing	438	98	8	5, 14	2, 372	0.92
At least one redflag event	10	2	8	6, 11	3, 118	
Number of redflag events related to fever						
0 redflag event/missing	446	99	8	5, 14	2, 372	0.22
At least one redflag event	2	0.4	16	10, 22	10, 22	

Table 2 continued

Interstage data: length of stay following S2P (days)	*N*	%	Median LOS	IQR	Range	*p* Value
Unscheduled procedures during IS1						
Cardiac surgery						
Yes	50	11	12	6, 23	3, 91	0.025
Missing or not indicated	398	89	7	5, 13	2, 372	
Cardiac catheterization						
Yes	71	16	11	7, 22	3, 372	0.0002
Missing or not indicated	377	84	7	5, 12	2, 370	
Home surveillance prior to Glenn						
Type						
Oxygen saturation and weight	323	72	8	5, 14	2, 372	0.24
Oxygen saturation only	41	9	8	6, 13	3, 107	
Unknown surveillance method	84	19	7	5, 19	3, 185	
Frequency						
Daily	251	56	8	6, 14	2, 372	0.0014
Other than daily	197	44	7	5, 14	2, 185	

Table 3 Stage 2 palliation, median length of stay (median LOS) in the hospital following stage 2 palliation (S2P)

	N	%	Median LOS	IQR	Range	*p* value
Type of S2P						
Unilateral, bidirectional Glenn/hemi-Fontan	344	77	8	5, 14	2, 372	0.54
Bilateral, bidirectional Glenn/hemi-Fontan	99	21	8	6, 15	3, 370	
Unknown	5	1	6	4, 7	4, 8	
*Oxygen saturation at discharge following S2P**						
<75 %	26	6	10	6, 17	2, 82	0.07
75–85 %	345	77	8	6, 15	2, 372	
>85 %	69	15	7	5, 10	3, 370	
Additional surgical procedure during S2P						
Additional procedure performed during S2P	134	30	10	7, 18	3, 370	<0.0001
Not indicated	314	70	7	5, 12	2, 372	
Septectomy	20	4	13	8, 29	4, 70	0.003
Not indicated	428	96	8	5, 14	2, 372	
Arch repair	17	4	11	8, 15	3, 181	0.08
Not indicated	431	96	7	5, 14	2, 372	
Pulmonary artery angioplasty	96	21	9	6, 15	3, 370	0.012
Not indicated	352	79	7	5, 13	2, 372	
Atrioventricular valve repair during S2P	25	6	11	7, 25	4, 91	0.005
Not indicated	423	94	7	5, 14	2, 372	

*$N = 8$ with missing oxygen saturation at discharge following S2P

down unit prior to discharge to home following S2P) (8 %), cardiac arrest (2 %), ECMO (0.2 %), performance of a cardiac catheterization (without reported intervention) (10 %), reoperation (7 %), the need for a non-oral feeding method following S2P (55 %), the performance of a major procedure (12 %) and the development of a major complication (32 %) were also evaluated. Cardioversion (1 %), thoracocentesis (2 %), and

bronchoscopy (3 %) were additional reported post operative procedures (Table 5).

LOS following the S2P did not vary by the type of S2P procedure performed. Specifically, LOS following unilateral BDG, bilateral BDG, unilateral HFP, and bilateral HFP was not significantly different ($p = 0.16$). Similarly, there was no difference in LOS following S2P when we linked unilateral BDG with unilateral HFP or bilateral BDG with bilateral HFP ($p = 0.54$). However, the performance of additional procedures, such as atrial septectomy, pulmonary artery angioplasty, and atrioventricular valve repair at the time of S2P surgery was associated with greater LOS following S2P (10 vs. 7 days; $p < 0.0001$) (Table 3). Aortic arch repair at the time of S2P was not associated with increased LOS ($p = 0.08$).

The use of vasoactive agents following the S2P was common. With the exception of dobutamine, norepinephrine, and Nipride, the use of vasoactive agents was associated with greater LOS (Table 4). The use of multiple vasoactive agents was also associated with greater LOS, such that the more agents used, the greater the LOS following S2P ($p < 0.0001$) (Table 4).

The need for re-admission to the ICU from the ward or step-down unit ($p < 0.0001$) and cardiac arrest ($p = 0.0003$) were associated with increased LOS. In addition, the need to perform a repeat surgery or cardiac catheterization following the S2P was associated with increased LOS ($p < 0.0001$ and $p = 0.0025$, respectively) (Tables 4, 6). Failure to detect a significant trend in LOS following S2P for those requiring ECMO may have been related to insufficient sample size ($p = 0.14$) (Table 4).

Non-oral nutritional modes including feeding via placement of a nasogastric tube/nasojejunal tube, the use of total parenteral nutrition, or feeding via placement of a gastrostomy tube occurred in 55 % of cases. The use of a non-oral method for feeding was associated with prolonged LOS (11 vs. 6 days; $p < 0.0001$).

Major postoperative procedures were carried out 12 % of the time and included but were not limited to cardioversion, pericardiocentesis, thoracocentesis, bronchoscopy, and tracheostomy. Median LOS following S2P if an additional procedure was performed was 28 versus 7 days ($p < 0.0001$) (Table 5).

Major complications occasionally arose following the S2P (32 %), such as the development of seizure, the need for pacing or dialysis, pneumonia, vocal cord injury, or pneumothorax. In general, the development of any major complication following the S2P was associated with increased LOS ($p < 0.0001$) (Table 5). Similarly, the need for a post-S2P cardiac catheterization with intervention such as aortic arch dilation, coiling of aortopulmonary collaterals, pulmonary artery dilation, and pulmonary artery stent placement was associated with increased LOS following S2P (Table 6).

Multivariate Analysis

Univariate analysis revealed 18 distinct variables associated with statistically significant differences in LOS following the S2P procedure. Using logistic regression and employing a forward selection method (outcome variable: stay greater than 14 days), we found that only four variables were predictive of prolonged LOS following the S2P. Variables associated with prolonged LOS following the S2P procedure included reoperation (OR 8.0, $p = 0.003$), the need for an additional postoperative cardiac catheterization including with intervention (OR 4.6, $p = 0.0051$), utilization of a non-oral method of nutrition following S2P (OR 5.0, $p = 0.0005$), and the development of a postoperative complication following S2P (OR 5.0 $p < 0.0001$) (Figure 1).

According to multivariate analysis results, age at surgery, the presence of a non-cardiac anomaly, site participant volume, redflag event related to breathing, CPB time (data not shown), the number of vasoactive agents used, the use of particular medications during IS1, the need to perform an unscheduled cardiac catheterization or surgery during IS1, surveillance frequency during IS1, performance of additional procedures, more than 1 ICU admission, and the performance of a major procedure following S2P were not associated with greater LOS.

Discussion

The S2P includes the BDG and the HFP. The BDG and HFP are currently accepted as stage 2 palliative approaches for the management of children with HLHS and HLHS variant anatomy [2, 12, 20]. Complications can and do arise following S2P, contributing to greater LOS and increased morbidity [1, 3, 9, 22]. In this paper, we identify factors associated with prolonged LOS following the S2P but exclude participants who underwent S2P following the hybrid procedure in order to evaluate a more homogeneous population. The goal of our study is to improve outcome, decrease cost, and improve resource utilization following S2P. We found that the greatest predictors of prolonged stay following S2P were the need for reoperation, the need for additional postoperative cardiac catheterization, the use of non-oral methods for providing nutrition, and the development of postoperative complications (Fig. 1).

Our study is not the first to attempt to identify predictors of prolonged stay following the S2P procedure, but it is one of the few to consider S1P, IS1, and S2P in the identification of predictors of prolonged LOS. Menon et al. [24]

Table 4 Post-stage 2 palliation management, median length of stay (median LOS) in the hospital following stage 2 palliation (S2P)

Bidirectional Glenn procedure	*N*	%	Median LOS	IQR	Range	*p* value
Vasoactive agent use						
Milrinone	401	90	8	6, 14	3, 372	0.0004
No milrinone	47	10	6	4, 9	2, 31	
Epinephrine	105	23	10	6, 21	3, 185	<0.0001
No epinephrine	343	77	7	5, 12	2, 372	
Dopamine	157	35	9	6, 17	3, 181	0.004
No dopamine	291	65	7	5, 11	2, 372	
Dobutamine	13	3	5	4, 11	2, 18	0.05
No dobutamine	435	97	8	5, 14	2, 372	
Norepinephrine	3	1	8	8, 28	8, 28	0.35
No norepinephrine	445	99	8	5, 14	2, 372	
Calcium	30	7	10	7, 19	3, 107	0.018
No calcium	418	93	7	5, 14	2, 372	
Vasopressin	6	1	20	17, 38	7, 46	0.012
No vasopressin	442	99	8	5, 14	2, 372	
Nipride	151	34	7	5, 11	3, 370	0.23
No Nipride	297	66	8	5, 15	2, 372	
Cumulative inotropic agent use: milr, epi, dopa, vaso, dobuta, norepi						
0	19	4.2	5	4, 8	2, 23	<0.0001
1	213	48	7	5, 11	2, 372	
2	177	40	8	6, 14	3, 185	
3	38	8.5	17	10, 33	4, 141	
4	1	0.2	8	n/a	n/a	
After the bidirectional Glenn surgery						
ICU hospitalization						
More than 1	34	8	37	14, 53	7, 185	<0.0001
Only 1	409	91	7	5, 12	2, 372	
Missing data	5	1	6	5, 11	5, 39	
Cardiac arrest						
Reported	7	2	39	14, 91	12, 118	0.0003
Not reported	441	98	7	5, 14	2, 372	
ECMO						
Yes	1	0.2	39	n/a	n/a	0.14
No	447	99	8	5, 14	2, 372	
Cardiac catheterization following S2P						
Yes	43	10	37	12, 67	4, 185	<0.0001
Not indicated	405	90	7	5, 12	2, 372	
Reoperation (excluding delayed sternal closure)						
Yes	32	7	42	19, 73	6, 370	<0.0001
No	416	93	7	5, 12	2, 372	
Reoperation type: Glenn revision						
Yes	2	0.4	36	n/a	33, 38	0.041
Not indicated	446	99	8	5, 14	2, 372	
Reoperation type: mediastinal debridement						
Yes	7	2	35	31, 53	14, 56	0.0002
Not indicated	441	98	7	5, 13	2, 372	
Reoperation type: exploration for suspected tamponade						
Yes	3	0.7	44	33, 185	33, 185	0.007

Table 4 continued

Bidirectional Glenn procedure	*N*	%	Median LOS	IQR	Range	*p* value
Not indicated	445	99.3	8	5, 14	2, 372	
Reoperation type: thoracic duct ligation						
Yes	2	0.4	147	108, 185	108, 185	0.016
Not indicated	446	99.6	8	5, 14	2, 372	
Reoperation type: diaphragm plication						
Yes	8	2	81	24, 144	17, 185	<0.0001
Not indicated	440	98	7	5, 13	2, 372	

Table 5 Major procedures following stage 2 palliation, median length of stay (median LOS) in the hospital following stage 2 palliation (S2P)

Nutrition, major procedures and reported complications following S2P	*N*	%	Median LOS	IQR	Range	*p* value
Postoperative nutrition						
Post-op nutrition, non-oral						
Reported	247	55	11	7, 22	2, 372	<0.0001
Not indicated	201	45	6	5, 8	2, 370	
Major procedures following S2P						
Reported	56	12	28	12, 52	2, 185	<0.0001
Not reported	392	88	7	5, 11	2, 372	
Major complication following S2P						
Reported	145	32	15	8, 33	3, 370	<0.0001
Not reported	303	68	6	5, 9	2, 372	

queried an earlier version of the NPC-QIC database with the goal of identifying factors associated with increased resource utilization at the time of S2P and immediately thereafter. In their study, they considered postoperative complications and procedures performed not as risk factors for prolonged stay after the S2P, but as outcome measures. They found that failure to meet target caloric intake during IS1 resulted in longer hospital stay. Other studies have identified factors associated with greater LOS following the S2P, including age <3 months and lower weight for age z-score at the time of S2P [4, 27]. Similar to prior studies, we did find that younger age at the time of S2P was associated with increased LOS by univariate but not by multivariate analysis. We also evaluated redflag events related to weight gain and home surveillance of weight as markers of whether or not a child was meeting recommended caloric intake; however, we were unable to find a relationship between impaired weight gain and LOS following S2P.

Demographic features, such as the presence of a non-cardiac anomaly, and their influence on LOS were also evaluated. Similar to prior published studies, we found that the presence of a non-cardiac anomaly was associated with prolonged LOS (by univariate analysis) following the S2P [26]. In a retrospective study by Patel et al. evaluating the impact of non-cardiac congenital and genetic abnormalities on outcome in HLHS, the presence of a non-cardiac abnormality was found to be associated with increased LOS after S2P. However, our study showed by multivariate analysis that this relationship was not preserved. When we considered other demographic features, such as race, we did not find an association with LOS, a result consistent with other published reports [15].

The potential impact of the S1P approach on LOS following S2P procedure was evaluated. Similar to other studies, we did not find an association between LOS following S2P among participants who had initially undergone S1P with Norwood/RV to PA conduit versus S1P with Norwood/BT shunt (median LOS of 7 and 8 days, respectively) [19].

It is clear that children who undergo routine monitoring during IS1 are more likely to survive the IS1 period [14]. However, what is not as well known is what impact this monitoring has on LOS and outcome following S2P. We found that in general, children who underwent daily monitoring had slightly longer LOS after S2P. The reason for this finding is not known, but could reflect (among other reasons) parental anxiety at the time of discharge or a higher-risk patient.

Previous single-center studies have sought to identify risk factors for morbidity and mortality after the S2P [3, 17, 22]. Kogon et al. found that cardiopulmonary bypass (CPB) time was associated with increased LOS [17]. Like Kogon et al.,

Table 6 Interventions following stage 2 palliation, median length of stay (median LOS) in the hospital following stage 2 palliation (S2P)

Post-S2P cardiac catheterization interventions	*N*	%	Median LOS	IQR	Range	*p* value
At least one post-S2P cardiac catheterization intervention performed						
Reported	128	29	8	6, 21	3, 370	0.0025
Not reported	320	71	7	5, 13	2, 372	
Coarctation/aortic arch dilation						
Reported	5	1	22	17, 82	7, 83	0.015
Not reported	443	99	8	5, 14	2, 372	
Coarctation/aortic arch stent						
Reported	1	0.21	185	n/a	n/a	0.086
Not reported	447	99.8	8	5, 14	2, 372	
Post-op AP collateral coil occlusion						
Reported	10	2	58	26, 108	8, 185	<0.0001
Not reported	438	98	7	5, 13	2, 372	
Post-op pulmonary artery dilation						
Reported	8	2	38	27, 113	17, 185	<0.0001
Not reported	440	98	7	5, 13	2, 372	
Post-op pulmonary artery stent						
Reported	9	2	24	10, 44	6, 185	0.004
Not reported	439	98	7	5, 14	2, 372	

There were no postoperative cardiac catheterization-related deaths

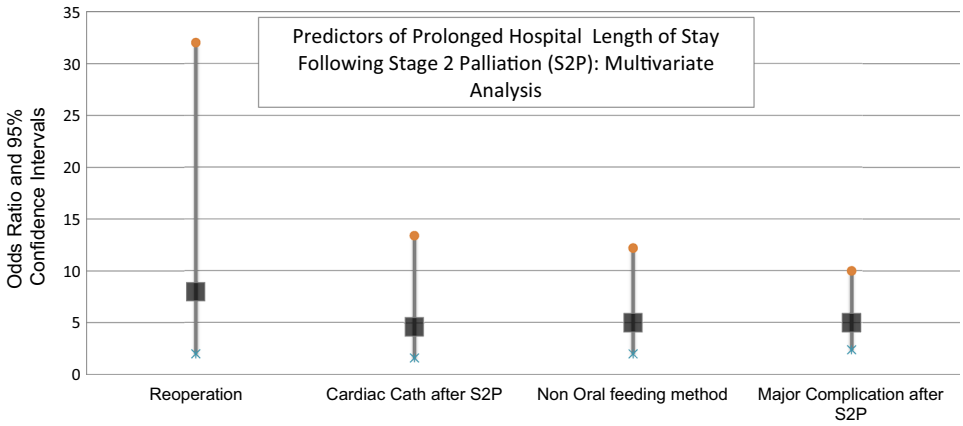

Fig. 1 Multivariate analysis. Predictors of prolonged length of stay (LOS) in the hospital following stage 2 palliation (S2P). Prolonged LOS is defined as hospital LOS >14 days. Variables included in logistic regression model were selected from univariate analysis. A forward selection method was used within logistic regression in order to select the best fit model ($p < 0.05$)

we found that greater CPB time was associated with prolonged LOS following S2P by univariate analysis, but not by multivariate analysis. The performance of additional procedures at the time of S2P was associated with greater LOS following the S2P. Other published reports have found that ventricular dysfunction and severe atrioventricular valve (AVV) regurgitation are associated with poorer outcomes following S2P [8, 22]. In our study, we found that the need for AVV surgery was associated with a significant increase in LOS (11 vs. 7 days; $p = 0.005$) by univariate analysis but not when we considered other factors in our multivariate analysis.

Cardiac catheterization prior to S2P surgery is standard. The cardiac catheterization is performed to evaluate the pulmonary anatomy and to assess the pulmonary vascular resistance [25]. While routine cardiac catheterization is expected prior to S2P, we found that the need for additional cardiac catheterization procedures during IS1 contributed to greater LOS following the S2P by univariate but not by multivariate analysis. The need for additional cardiac catheterization procedures following S2P was associated with greater LOS. The need for additional cardiac catheterization procedures performed post S2P may reflect additional anatomic or hemodynamic issues and thus contribute to increased LOS. Finally, while it is necessary to optimize a child's nutritional status following S2P, we found that additional procedures such as placement of feeding tubes are also associated with increased LOS [30].

There are several limitations to our study. First, there are inherent challenges with the use of a database. The NPC-QIC database includes only participants who were discharged to home following S1P. While the number of excluded participants may be small, the exclusion of non-discharged participants does lead to removal of a broader patient population. Additional limitations of our study include an inability to determine the exact reason a patient underwent an additional procedure, an additional ICU hospitalization (defined as more than one ICU discharge to the ward or step-down unit following S2P), or developed a postoperative complication.

Finally, the cost of caring for children with HLHS (and HLHS variant) is significant. Previously published studies have also determined the median LOS following the S2P procedure to be 8 days. Studies have estimated that the cost associated with this length of hospitalization is $82,174 [10]. This cost estimate does not include incremental costs associated with additional days in the hospital or additional procedures performed. When one considers that the S2P is only one of three major surgeries (at least) that a child will undergo, it is clear that identifying risk factors associated with greater LOS is important.

In conclusion, we found that the most important predictors of LOS following S2P are factors related to the management of patients immediately post-S2P. Further efforts to optimize patient management following S2P may lead to improved outcome, decreased resource utilization, and decreased cost.

Conflict of interest None.

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