

Predictors of Postoperative Rehabilitation Therapy Following Congenital Heart Surgery

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Background—Patients with congenital heart disease are at risk of motor, cognitive, speech, and feeding difficulties after cardiac surgery. Rehabilitation therapy could improve functional outcomes in this population if applied in the acute postcardiac surgical in-hospital stay. However, information on the types of acute postcardiac surgery therapy needs in children is scarce. Our goal was to describe rehabilitation therapy following congenital heart surgery and pre/intraoperative factors associated with need for therapy.

Methods and Results—This is a retrospective cohort study of patients <18 years undergoing heart surgery at our center from January 1, 2013 to January 31, 2015. Demographic, and pre-, intra-, and postoperative clinical and rehabilitation therapy (physical, occupational, speech, feeding therapy, and neurodevelopment intervention) data were collected. Need for rehabilitation therapy in the acute postoperative period, particularly following palliative repair, was the outcome variable in a multivariable logistic regression model to identify independent pre- and intraoperative factors associated with therapy. A total of 586 out of 1415 (41%) subjects received rehabilitation therapy postsurgery. Certain subgroups had increased rehabilitation therapy use such as neonates (80%). On multivariable analysis, palliative repair, prematurity, genetic syndrome, presurgical hospital stay of more than 1 day, and prolonged cardiopulmonary bypass time were independently associated with rehabilitation therapy.

Conclusions—Nearly half of patients who underwent post-congenital heart surgery received rehabilitation therapy. Frequency of use and types of therapy vary according to patient characteristics; however, certain pre- and intraoperative factors are associated with need for rehabilitation therapy, and may aid decision-making for appropriate resource allocation. (*J Am Heart Assoc.* 2018;7:e008094. DOI: 10.1161/JAHA.117.008094.)

Key Words: congenital heart disease • function • pediatrics • rehabilitation • surgery

Postcardiac surgery morbidity and mortality has decreased over the past decades in patients with congenital heart disease (CHD). In the United States, survival in the first year of life is 75.2% for those with complex CHD versus 97.1% for those with noncomplex CHD.¹

There is a growing body of research on long-term functional impairment following surgery in patients with CHD, particularly in neurodevelopment^{2–5} and exercise capacity.^{6,7} However, little is known about the acute impact of cardiac surgery on the immediate postoperative functional status and resultant rehabilitation use.

The ability to provide an early rehabilitation program with rehabilitation therapies (RT) such as physical, occupational, speech or feeding therapies, as well neurodevelopment assessment will allow us to positively impact functional deterioration following cardiac surgery and positively impact the child's development. RT may even decrease complications and length of stay (LOS) in the acute care facility.

Our objective was to better understand what types of RT are used and what factors are associated with an increased use of RT in the acute postoperative period in children following surgery for CHD.

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Accompanying Tables S1 through S3 are available at <http://jaha.ahajournals.org/content/7/10/e008094/DC1/embed/inline-supplementary-material-1.pdf>

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Clinical Perspective

What Is New?

- Acute functional impairment following cardiac surgery for congenital heart disease is common and requires further study to identify at-risk individuals and determine appropriate intervention strategies.
- Independent factors associated with higher use of rehabilitation therapy in patients with congenital heart disease following surgery on cardiopulmonary bypass include palliative repair, younger age, genetic syndrome, longer preoperative length of stay and, in patients outside the neonatal period, surgical residual lesions.
- Adverse events after surgery increase the likelihood of receiving rehabilitation therapy.

What Are the Clinical Implications?

- We can identify functionally vulnerable subgroups of patients with congenital heart disease undergoing heart surgery.
- Identification of patients who will most benefit from rehabilitation therapy can guide resource allocation and referral patterns.
- There is potential to improve overall patient outcomes and experience.

Methods

In accordance with the American Heart Association Transparency Guideline, we disclose here that the data will not be made available to other researchers for purposes of reproducing the results or replicating the procedure. The analytic methods are available below. As this was a single center retrospective review, there are no formal study materials to share such as a study protocol.

This is a retrospective descriptive study of RT use in consecutive patients who underwent surgery for congenital cardiac defects on cardiopulmonary bypass at Boston Children's Hospital. Institutional Review Board approval with waiver of consent was obtained for this study. We included patients <18 years of age with CHD who underwent first palliative or full (complete) repair of a congenital heart defect on cardiopulmonary bypass (CPB) between January 1, 2013 and January 31, 2015. We excluded patients who underwent placement of a ventricular assist device (VAD) before the first repair or who underwent primary cardiac or lung transplant to keep our patient sample as homogeneous as possible. The following data were collected:

Preoperative variables: included demographic data such as age at surgery, and sex. Additional variables included prematurity (defined as ≤ 36 weeks gestation), presence of genetic anomalies, preoperative LOS, and case complexity as

determined by the Society of Thoracic Surgeons-European Association of Cardio-Thoracic Surgery Congenital Heart Surgery (STAT) Mortality Categories.⁸ Documentation of preoperative functional status was often incomplete and therefore was not included.

Intraoperative variables: included CPB time, technical performance score (TPS)⁹ as a measure of residual disease, and cardiac physiology on completion of surgery (uni- versus biventricular circulation).

Postoperative variables: included postoperative LOS, postoperative adverse events, and type of RT.

Our primary outcome was use of RT in the postoperative period. The primary predictor for the main analysis was type of repair (ie, palliative versus complete repair).

Definitions

Rehabilitation therapy (RT): is a composite measure defined as having received physical, occupational, speech, feeding therapy, and/or neurodevelopment assessment during the postoperative period during hospitalization for index surgery. *Physical therapy (PT)* was provided for gross motor or gait impairments, *occupational therapy (OT)* for fine motor impairments or difficulties with activities of daily living, *feeding therapy (FT)* for feeding difficulties, failure to progress towards oral feeding or suspicion of aspiration, and *speech therapy (ST)* for communication or cognitive difficulties.

STAT mortality categories: These categories assign the risk of mortality associated with a particular procedure based on cumulative data collected in the Society of Thoracic Surgery Congenital Heart Surgery Database (STS-CHS) database. The risk of mortality increases as procedure complexity increases, with mortality category 1 having the lowest and 5 the highest mortality risk.⁸

Technical Performance Score (TPS): is an echocardiographic and clinical measure of residual disease. Each procedure is divided into subprocedures and each subprocedure is classified as Class 1 (trivial or no residua, optimal), Class 2 (minor residua, adequate), or Class 3 (major residua or unplanned pre-discharge catheter or surgical reintervention for residua, inadequate) based on postoperative echocardiographic findings. The final TPS score was based on subprocedure scores. The final TPS was Class 1 if all subprocedures were Class 1, Class 2 if or more subprocedures were Class 2, but none Class 3, and Class 3 if 1 or more subprocedures were Class 3.⁹

Postoperative adverse events: include extracorporeal membrane oxygenation, VAD, cardiac arrest, neurological events (including hypoxic-ischemic encephalopathy, intraventricular hemorrhage \geq grade 3, and stroke), and mortality or heart transplant after the index cardiac surgical intervention, and

before discharge from the hospital. Because mortality was low, we combined postoperative adverse events and mortality to form a composite outcome for analyses.

Statistical Analysis

Categorical variables are summarized as numbers and percentages and continuous variables as medians and ranges. Proportions and odds ratios are presented with 95% confidence intervals.

Logistic regression was used to identify independent predictors of the primary outcome (RT use yes/no) and also for grouped components of RT (ie, [1] PT and OT, [2] FT and ST, and [3] neurodevelopmental intervention).

Univariate analysis was first performed, along with the evaluation of age×predictor interaction term for each predictor. Factors included in the model construction were pre- and intraoperative factors, determined by a stepwise logistic regression to create a multivariable model. Postoperative factors such as extracorporeal membrane oxygenation, VAD, transplant, and neurologic events post-repair were not used in construction of the multivariable model because they reside in the causal pathway to the primary outcome. Effect sizes are expressed using the estimated odds ratio and 95% confidence interval.

We also examined the association between mortality and adverse events as outcomes with rehabilitation therapy as the predictor, using a Fisher exact test. Because of the low mortality rate, we also examined the composite outcome of mortality and adverse events.

We also examined the interaction of each predictor with age group (neonate versus non-neonate). Factors included in the model construction were clinically relevant pre- and intraoperative factors, confirmed by a stepwise logistic regression to create a multivariable model. Postoperative factors such as extracorporeal membrane oxygenation, VAD, transplant, and neurologic events postrepair were not used in construction of the multivariable model because they reside in the causal pathway to the primary outcome. Additional analysis was performed to identify collinearity among the preoperative and intraoperative predictors and the postoperative adverse events.

A *P* value of 0.05 or less was considered to be statistically significant. We analyzed the data using SAS[®] version 9.4 (SAS Institute Inc, Cary, NC).

Results

Patient Characteristics

A total of 2091 congenital cardiac surgical procedures were performed at Boston Children's Hospital between January 1,

2013 and January 31, 2015; of those, 1415 surgeries were first palliative or first repair on cardiopulmonary bypass. Figure displays the total cohort and the final cohort and reasons for exclusion. Most patients (54%) who underwent heart surgery on bypass were ≤2 years of age. Of the 1415 in the analytic cohort, 586 (41%) patients received at least 1 type of RT: 91 (6.4%) PT only, 106 (7.4%) FT only, 126 (8.9%) neurodevelopmental intervention only, ST only 5 (0.3%), and the remaining 258 (18.2%) patients received more than 1 type of therapy. After exclusion of patients with missing data for the covariates of interest, 1379 were included in the final multivariable analysis.

Neonates were most likely to receive RT (80%). Non-neonates ≤2 years of age more often received RT than those older than 2 years (≥50% versus 21%, Table 1). The other subgroup of patients who were more likely to receive rehabilitation services included patients who underwent palliative surgery (60% versus 37% who had full repair).

Types of RT

Age was associated with not only the prevalence of RT, but also the type of RT (Table 2). Feeding was the most common RT in neonates (58%). In patients over age 2 years, PT was the most common form of therapy (19% underwent PT). Feeding was a relatively common therapy in several other subgroups of patients (ie, palliative surgery, and higher STAT and TPS category). Patients who had a neurologic event (79%), or required a post-CHD surgery transplant (89%) had a high need for RT.

Risk Factors Related to Increased Use of RT

Prematurity, genetic syndrome, higher disease complexity score, surgery not on the same day of hospital admission,

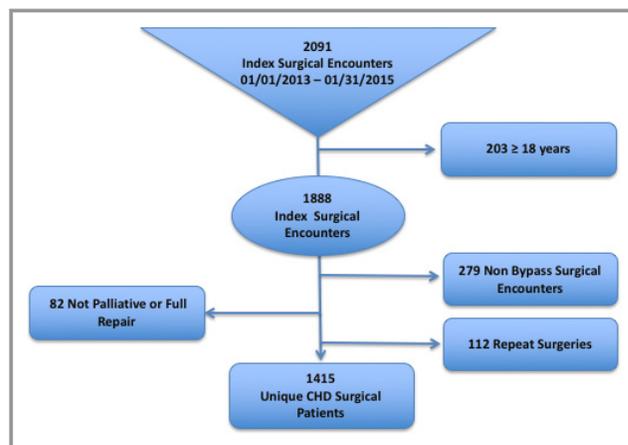


Figure. Flow diagram depicting selection of subjects for analytic cohort. The final numbers of subjects represent those who met predetermined inclusion and exclusion criteria.

Table 1. Baseline Patient Characteristics (N=14 15)

Variable	N (%)	N (%) Receiving RT
Type of surgery		
Full repair	1162 (82%)	435 (37%)
Palliative	253 (18%)	151 (60%)
Preoperative factors		
Sex (male)	627 (44%)	252 (40%)
Gestational age		
<37 wks	116 (8%)	87 (75%)
≥37 wks	1299 (92%)	499 (38%)
Age at surgery		
Median age at surgery: median (IQR)	1.6 (0.3, 6.1)	0.4 (0.0, 1.8)
≤1 mo	226 (16%)	180 (80%)
>1 mo to ≤2 y	530 (38%)	266 (50%)
>2 to ≤12 y	494 (35%)	107 (22%)
>12 to ≤18 y	165 (12%)	33 (20%)
Genetic syndrome		
Present	292 (21%)	150 (51%)
Absent	1123 (79%)	436 (39%)
Case complexity (STAT)		
Median STAT score, median (IQR)	2.0 (1.0, 4.0)	3.0 (2.0, 4.0)
STAT Category 1	468 (34%)	108 (23%)
STAT Category 2	380 (28%)	121 (32%)
STAT Category 3	142 (10%)	90 (63%)
STAT Category 4	323 (23%)	195 (60%)
STAT Category 5	71 (5%)	50 (70%)
Preoperative LOS, median (IQR)	1.0 (1.0, 3.0)	3.0 (1.0, 6.0)
≤1 d	882 (62%)	210 (24%)
>1 d	533 (38%)	376 (71%)
Intraoperative factors		
TPS		
Class 1 optimal	640 (45%)	227 (35%)
Class 2 adequate	432 (31%)	150 (35%)
Class 3 inadequate	136 (10%)	77 (57%)
Class 4 no TPS developed	202 (14%)	128 (63%)
CPB time, mean±SD	126.1±65.1	144.0±66.8
CPB time quartile group		
Q1 (<77 min)	346 (24%)	94 (27%)
Q2 (<116 min)	361 (26%)	115 (32%)
Q3 (<159 min)	352 (25%)	174 (49%)
Q4 (≥159 min)	356 (25%)	203 (57%)

Continued

Table 1. Continued

Variable	N (%)	N (%) Receiving RT
Postoperative factors		
Anatomy		
Biventricle	1178 (83%)	446 (38%)
Univentricle	237 (17%)	140 (59%)
ECMO*		
Yes	44 (3%)	28 (64%)
No	1371 (97%)	558 (41%)
VAD*		
Yes	8 (0.5%)	6 (75%)
No	1407 (99.5%)	580 (41%)
Cardiac arrest		
Yes	54 (4%)	47 (74%)
No	1361 (96%)	546 (40%)
Neurologic events		
Yes	70 (5%)	54 (77%)
No	1345 (95%)	532 (40%)
Heart transplant*		
Yes	18 (1%)	16 (89%)
No	1397 (99%)	570 (41%)

CPB indicates cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation; IQR, interquartile range; LOS, length of stay; RT, rehabilitation therapies; STAT, Society of Thoracic Surgeons-European Association of Cardio-Thoracic Surgery Congenital Heart Surgery Mortality Categories; TPS, technical performance score; VAD, ventricular assist device.

*Instituted in the postoperative period following index cardiac repair.

major residua as indicated by Class 3 TPS, upper quartile of bypass time (≥159 minutes), univentricular anatomy, and occurrence of postoperative adverse events were all associated with a higher need for RT. The findings of univariable analysis are depicted in (Table 3).

Univariate analysis of 3 outcomes related to specific types of therapy as follows: (1) PT and OT, (2) FT and ST, and (3) neurodevelopment intervention (Table 4 and Tables S1 through S3) was performed. Several perioperative factors are associated with all 3 rehabilitation services: Preterm birth, palliative repair, higher (worse) disease complexity, presurgery LOS >1 day, inadequate/no TPS, and prolonged bypass time. Younger age is significantly associated with receipt of FT/ST or neurodevelopment intervention, but is not related to PT/OT. The presence of genetic syndrome is associated with receipt of PT/OT, FT/ST, but is not associated with higher odds of neurodevelopment intervention.

Mortality is not associated with any 1 of the 3 specific types of rehabilitation, but LOS and the composite end point of mortality/adverse events are associated with receiving RT ($P<0.001$).

Table 2. Distribution of Types of RT Use by Subgroups

Variable	N	Any (%)	PT (%)	OT (%)	FT (%)	ST (%)	ND (%)
Type of surgery							
Palliative	253	60	27	15	37	5	33
Complete	1162	37	16	5	20	3	18
Preterm							
Gestation age <37 wks	116	75	28	15	53	2	41
Gestation age ≥37 wks	1299	38	17	6	21	4	19
Genetic syndrome							
Present	292	51	29	13	33	6	18
Absent	1123	39	15	5	21	2	22
Age							
<30 d	226	80	10	7	58	1	57
31 d to 2 y	530	50	19	9	29	3	29
>2 to ≤12 y	494	22	19	5	8	4	3
>12 to ≤18 y	165	20	19	2	4	4	1
STAT							
STAT Category 1	468	23	7	2	10	1	12
STAT Category 2	380	32	15	4	16	2	15
STAT Category 3	142	63	28	8	43	6	30
STAT Category 4	323	60	27	12	35	5	33
STAT Category 5	71	70	21	17	60	6	45
TPS							
Class 1 optimal	640	36	13	4	20	2	17
Class 2 adequate	432	35	12	5	18	3	19
Class 3 inadequate	136	57	36	16	38	7	26
ECMO	44	64	50	30	43	14	41
VAD	8	75	75	38	50	38	13
Heart transplant	18	89	89	33	39	33	22
Neuro events	70	77	63	44	51	17	30

ECMO indicates extracorporeal membrane oxygenation; FT, feeding therapy; N, number; ND, neurodevelopmental assessment; OT, occupational therapy; PT, physical therapy; RT, rehabilitation therapy; ST, speech therapy; STAT, Society of Thoracic Surgeons-European Association of Cardio-Thoracic Surgery Congenital Heart Surgery Mortality Categories; TPS, technical performance score; VAD, ventricular assist device.

Interactions With Age

Four predictors of RT had an interaction with neonate versus non-neonate age group. Preterm birth, preoperative LOS >1 month, TPS, and CPB time were risk factors for RT only in the non-neonate group (interaction $P=0.001$, 0.007, 0.002, and 0.04, respectively).

Determination of Independent Factors Associated With Postsurgical RT Use

The multivariable logistic regression model (Table 5) of pre- and intraoperative factors associated with receipt of RT showed that patients who had palliative repair were 1.84

times more likely to receive RT compared with those who underwent complete repair. Other independent factors associated with higher odds of receiving RT were the following: prematurity, genetic syndrome, presurgical hospital stay of more than 1 day, and prolonged CPB time. In addition, TPS was associated with RT, but the direction of effect differed for neonates and non-neonates. Among neonates, inadequate TPS predicted a lower likelihood for receipt of RT (versus optimal, odds ratio=0.23). The decreased likelihood of RT in neonates with an inadequate TPS may be related to the higher mortality rate in this small subgroup. This multivariable model has a good predictive power, with a c-statistic of 0.81.

Table 3. Univariate Logistic Regression Results for Receipt of Rehabilitation Therapies N=1415

Variable	N	OR	95% CI	P Value	R ^{2*}
Primary predictor					
Full vs palliative repair	1415	0.40	0.31, 0.53	<0.001*	0.04
Preoperative factors					
Preterm birth	1415	4.81	3.11, 7.43	<0.001*	0.06
Age at surgery, group				<0.001*	0.24
≤1 mo	226	15.65	9.49, 25.82		
>1 mo to ≤2 y	530	4.03	2.65, 6.12		
>2 to ≤12 y	494	1.11	0.71, 1.71		
>12 to ≤18 y	165	Ref			
Genetic syndrome	1415	1.66	1.28, 2.16	<0.001*	0.01
STAT mortality category	1384			<0.001*	0.17
STAT Category 1	468	Ref			
STAT Category 2	380	1.56	1.15, 2.11		
STAT Category 3	142	5.77	3.85, 8.64		
STAT Category 4	323	5.08	3.73, 6.92		
STAT Category 5	71	7.94	4.56, 13.80		
Preoperative hospital stay, d	1415	1.43	1.35, 1.52	<0.001*	0.24
Intraoperative factors					
TPS	1410			<0.001*	0.07
Class 1 optimal	640	Ref			
Class 2 adequate	432	0.97	0.75, 1.25		
Class 3 inadequate	136	2.37	1.63, 3.46		
Class 4 no TPS	202	3.15	2.27, 4.37		
CPB time (per 1-h increase)	1415	1.58	1.42, 1.76	<0.001*	0.07
Postoperative factors					
Single ventricle/BiV	1415	2.37	1.78, 3.15	<0.001*	0.04
ECMO [†]	1415	2.42	1.26, 4.63	0.007*	0.01
VAD [†]	1415	4.27	0.86, 21.24	0.08	0.004
Cardiac arrest	1415	4.26	2.30, 7.91	<0.001*	0.02
Neurological events	1415	5.16	2.92, 9.11	<0.001*	0.04
Heart transplant [†]	1415	11.59	2.66, 50.53	0.001*	0.001

BiV indicates biventricular; CI, confidence interval; CPB, cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation; N, number of patients with data available in each category; OR, odds ratio; STAT, Society of Thoracic Surgeons-European Association of Cardio-Thoracic Surgery Congenital Heart Surgery Mortality Categories; TPS, technical performance score; VAD, ventricular assist device.

*Statistically significant.

[†]Instituted in the postoperative period following index cardiac repair. R^{2*}: max-rescaled R².

Discussion

While several studies have explored late neurodevelopmental outcomes²⁻⁵ and exercise training on older patients with CHD after surgery,¹⁰⁻¹⁵ little has been published on the acute impact on functional status following CHD surgery, and the associated RT use in the immediate postoperative period.

In our study, almost half of our patients needed some form of RT. The type of therapy received varied, depending on the

age, disease complexity, and adequacy of repair as measured by TPS. Certain preoperative and intraoperative factors, not surprisingly, are independently related to receipt of RT such as palliative repair, younger age, genetic syndrome, longer preoperative LOS, and residual lesions (TPS). Premature infants had 2 times the odds of requiring RT. In patients older than 1 month, major residua as indicated by Class 3 TPS had twice the odds of needing RT. However, the use of RT in the acute setting could also be related to postoperative events

Table 4. Risk Factors for Types of RT

Risk Factor	Any Rehab	PT/OT	FT/ST	Neuro
Palliative	<0.001*	<0.001*	<0.001*	<0.001*
Preterm birth	<0.001*	0.001*	<0.001*	<0.001*
Younger age at surgery (continuous)	<0.001*	0.79	<0.001*	<0.001*
Neonates	<0.001*	0.01*	<0.001*	<0.001*
Sex	0.41	0.95	0.38	0.50
Genetic syndrome	<0.001*	<0.001*	<0.001*	0.19
Higher STAT category	<0.001*	<0.001*	<0.001*	<0.001*
TPS Class 3	<0.001*	<0.001*	<0.001*	<0.001*
Preop stay >1 d	<0.001*	<0.001*	<0.001*	<0.001*
Longer bypass time	<0.001*	<0.001*	<0.001*	<0.001*
Longer postop LOS	<0.001*	<0.001*	<0.001*	<0.001*
ECMO postsurgery	0.007*	<0.001*	0.003*	0.004*
ECMO collapsed	0.003*	<0.001*	0.001*	0.001*
VAD collapsed	0.08	0.001*	0.11	0.56
Cardiac arrest	<0.001*	<0.001*	<0.001*	<0.001*
Neurological events	<0.001*	<0.001*	<0.001*	0.06
Heart transplant	0.001*	<0.001*	0.05*	0.89

ECMO indicates extracorporeal membrane oxygenation; FT, feeding therapy; LOS, length of stay; Neuro, neurodevelopment; OT, occupational therapy; PT, physical therapy; RT, rehabilitation therapy; ST, speech therapy; STAT, Society of Thoracic Surgeons-European Association of Cardio-Thoracic Surgery Congenital Heart Surgery Mortality Categories; TPS, technical performance score; Uni, univentricular repair; VAD, ventricular assist device.

*Statistically significant.

such as neurologic insult/injury, deconditioning, and prolonged ventilation with/without use of paralytics. Some of the adverse postoperative events can be attributed to 1 or more of the preoperative factors listed above, and these may be the driving force for the referral to RT (Table 5).

Feeding difficulties are especially common and relevant in patients under a month of age (58% in our series). These difficulties might be subtle and sometimes go unnoticed. Injury of the recurrent laryngeal nerve, deconditioning, prolonged intubation, breathing difficulties, and neurodevelopment delays have correlated with feeding difficulties.^{16–19} Feeding issues in older patients, however, might be a consequence of an adverse neurological event with an impairment of acquired function as opposed to the lack of development of functional milestones in the neonatal period. This may contribute to increased hospital LOS in this patient population and can also lead to adverse events such as aspiration pneumonia. Nasogastric tube feeding at discharge and in palliative repairs has been related to increased readmission rates in post-CHD surgery. Developmental delays have been demonstrated in CHD patients with worse growth and those who require device-assisted feeding.²⁰ Furthermore, readmission has important

Table 5. Multivariable Logistic Regression Model of Pre- and Intraoperative Factors Associated With Receipt of RT (N=1379, Max-Rescaled $R^2=0.35$, c-statistic=0.81)

Variable	OR	95% CI	P Value
Palliative repair vs full repair	1.97	1.41, 2.75	<0.001
Preterm birth	2.46	1.49, 4.06	<0.001
Genetic syndrome: yes vs no	1.70	1.25, 2.31	<0.001
Preoperative LOS >1 d vs ≤1 d	3.83	2.83, 5.18	<0.001
CPB time (per 30-min increase)	1.13	1.06, 1.20	<0.001
TPS			0.291
Neonates			0.006
TPS x age group			0.005
Among neonates			
1: Optimal	Ref		
2: Adequate	0.98	0.37, 2.59	
3: Inadequate	0.23	0.07, 0.79	
4: No TPS developed	0.82	0.37, 1.82	
Among age >1 mo			
1: Optimal	Ref		
2: Adequate	1.00	0.73, 1.39	
3: Inadequate	2.01	1.26, 3.21	
4: No TPS developed	2.08	1.31, 3.29	

CI indicates confidence interval; CPB, cardiopulmonary bypass; LOS, length of stay; OR, odds ratio; RT, rehabilitation therapy; TPS, technical performance score.

healthcare and financial implications for our patients. Therefore, careful evaluation and treatment of feeding difficulties should be incorporated into the acute postsurgical management, especially in patients under a month of age.

Adverse mid- to long-term neurodevelopment outcomes have also been correlated with pre- and intraoperative factors such as prematurity, genetic syndrome, prolonged CPB times, TPS, postsurgical adverse events, particularly need for VAD or extracorporeal membrane oxygenation, and prolonged LOS.^{9,21–25}

Functional impairment is higher than we suspected in the immediate postoperative period. This is probably because of a combination of pre-, intra-, and postoperative factors. Therefore, therapy needs are often underestimated in the acute hospital setting after cardiac surgery. Our data demonstrate RT therapy use in almost 50% of patients undergoing surgery and allows us a better understanding of the RT used and resources (human/economic) needed. Understanding pre- and intraoperative factors associated with an increased use of RT might allow us to manage our patients more effectively and ensure adequate resource allocation to meet their needs.

Future direction includes establishment of formal rehabilitation protocols for all patients undergoing CHD surgery with

initiation of preoperative and early postoperative RT, followed by lifelong rehabilitation assessment and management in high-risk patients.²⁶ Further studies need to be performed to evaluate the impact of RT on acute postcardiac surgery patients on LOS, complications, and functional outcomes. Implementation of early RT may decrease functional deficits associated with surgery, decrease comorbidities and LOS, as well as improve functional outcomes. Financial analysis models have shown that investment in early rehabilitation programs in the intensive care unit for adults has the potential to generate substantial net cost savings for hospitals while improving patient outcomes.²⁷ While deconditioning and critical neuropathy are the biggest issues in adult postcardiac surgery patients,^{28,29} our data highlight the important differences in the adult patient population in whom PT is the most common therapy used compared with patients following congenital heart surgery where they might need a combination of interventions. Thus, pediatric cardiac rehabilitation programs have to be multidisciplinary and personally tailored not only by the type of CHD but also by age.

Limitations

Our study has the following limitations. We included only patients who underwent surgery on CPB. There may have been patients who had surgery off pump (eg, Blalock Taussig shunts and PA bands) who would likely have benefited from RT, while the majority of patients who had procedures such as coarctation repair, pacemaker procedures, and so on likely did not receive RT. We plan to collect data prospectively on all patients moving forward and will include this group in our analysis then. This is a retrospective descriptive review of therapy use in a single institution and therefore may not be generalizable to all centers. At our center currently, PT, OT, ST, and FT are not offered universally but are consult based; thus, more subtle functional impairments may have been missed. However, neurodevelopment assessment is standard in our center for all patients undergoing surgery under 1 year of age. Therefore, the percentage of patients evaluated may be higher than in other centers. The analysis of association between TPS and rehabilitation therapy is exploratory and will need future prospective multicenter studies. We chose not to include factors such as socioeconomic status, which may impact long-term (outpatient) therapy needs as we were primarily interested in acute therapy use. Functional status before surgery was not always clear in documentation and therefore not included in the analysis; however, this may be an important predictor of postoperative rehabilitation therapy needs. Further prospective research with long-term follow-up is required to understand the early, mid-, and long-term effects of RT. Multidisciplinary rehabilitation intervention in the acute post-CHD surgery

setting may be important in not only reducing resource use in this critically ill population, but also in improving functional outcomes in the long term.

Conclusions

Rehabilitation interventions are frequently received in the acute postoperative period following congenital cardiac operations. Palliative repair, younger age, genetic syndrome, longer preoperative LOS and, in patients outside the neonatal period, surgical residua (TPS) are independently associated with higher use of RT in patients with CHD who undergo cardiac surgery on CPB. Adverse events after surgery are also associated with an increased likelihood of using RT. These data allow us to identify functionally vulnerable subgroups, to better plan for perioperative care, and to tailor the rehabilitation program to each patient's need. Future prospective studies are planned to describe the effectiveness of early postsurgical rehabilitation interventions both in the short and long term.

Disclosures

None.

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SUPPLEMENTAL MATERIAL

Table S1. Factors associated with Physical and/or Occupational Therapy.

Risk Factor	Odds ratio 95% interval	p
Palliative	0.46 (0.34, 0.63)	<.001
Preterm birth	2.01 (1.31, 3.08)	0.001
Younger Age at surgery (continuous)	1.00 (0.97, 1.02)	0.79
Neonates	0.57 (0.37, 0.87)	0.01
Sex	0.99 (0.76, 1.30)	0.95
Genetic syndrome	2.40 (1.78, 3.23)	<.001
Higher STAT category	1.55 (1.39, 1.73)	<.001
TPS Class 3	1.11 (0.70, 1.75)	<.001
Pre-op stay>1 day	0.36 (0.28, 0.48)	<.001
Longer Bypass time	1.25 (1.18, 1.33)	<.001
Longer Post-op LOS	1.07 (1.06, 1.08)	<.001
ECMO post-surgery	4.83 (2.56, 9.11)	<.001
VAD	13.86 (2.78, 69.06)	0.001

Cardiac arrest	4.57 (2.63, 7.93)	<.001
Neurological events	10.36 (6.19, 17.34)	<.001
Heart Transplant	38.56 (8.81, 168.81)	<.001

ECMO: Extracorporeal Membrane Oxygenation; TPS: technical performance score Biv: Biventricular

repair; Uni: Univentricular repair; VAD: Ventricular Assist Device

Table S2. Factors associated with Feeding and/or Speech Therapy.

Risk Factor	Odds ratio 95% interval	p
Palliative	0.43 (0.32, 0.58)	<.001
Preterm birth	4.00 (2.71, 5.89)	<.001
Younger Age at surgery (continuous)	0.79 (0.75, 0.83)	<.001
Neonates	6.20 (4.58, 8.40)	<.001
Sex	0.90 (0.70, 1.15)	0.38
Genetic syndrome	1.93 (1.45, 2.55)	<.001
Higher STAT category	1.81 (1.63, 2.00)	<.001
TPS Class 3	0.94 (0.60, 1.47)	<.001
Pre-op stay>1 day	0.12 (0.09, 0.16)	<.001
Longer Bypass time	1.25 (1.18, 1.32)	<.001
Longer Post-op LOS	1.12 (1.10, 1.13)	<.001
ECMO post-surgery	2.65 (1.40, 4.99)	0.003
VAD	3.15 (0.78, 12.66)	0.11

Cardiac arrest	4.19 (2.41, 7.26)	<.001
Neurological events	3.81 (2.34, 6.19)	<.001
Heart Transplant	2.54 (0.99, 6.48)	0.05

ECMO: Extracorporeal Membrane Oxygenation; TPS: technical performance score Biv: Biventricular

repair; Uni: Univentricular repair; VAD: Ventricular Assist Device

Table S3. Factors associated with Neurodevelopment.

Risk Factor	Odds ratio 95% interval	p
Palliative	0.45 (0.33, 0.61)	<.001
Preterm birth	2.99 (2.02, 4.44)	<.001
Younger Age at surgery (continuous)	0.38 (0.31, 0.46)	<.001
Neonates	8.14 (5.97, 11.10)	<.001
Sex	0.91 (0.71, 1.18)	0.5
Genetic syndrome	0.80 (0.58, 1.12)	0.19
Higher STAT category	1.61 (1.46, 1.79)	<.001
TPS Class 3	0.68 (0.42, 1.11)	<.001
Pre-op stay>1 day	0.17 (0.13, 0.22)	<.001
Longer Bypass time	1.13 (1.06, 1.19)	<.001
Longer Post-op LOS	1.03 (1.02, 1.04)	<.001
ECMO post-surgery	2.61 (1.37, 4.97)	0.004

VAD	0.54 (0.07, 4.39)	0.56
Cardiac arrest	2.73 (1.56, 4.77)	<.001
Neurological events	1.67 (0.98, 2.83)	0.06
Heart Transplant	1.08 (0.35, 3.31)	0.89

ECMO: Extracorporeal Membrane Oxygenation; TPS: technical performance score Biv: Biventricular repair; Uni: Univentricular repair; VAD: Ventricular Assist Device