Cardiology in the Young

cambridge.org/cty

Analysis of factors associated with prolonged post-operative course after surgical repair of aortic coarctation

Santosh Kaipa[1], Mouhammad Yabrodi[1], Brian D. Benneyworth[1], Eric S. Ebenroth[2] and Christopher W. Mastropietro[1]

[1]Department of Pediatrics, Division of Critical Care, Indiana University School of Medicine, Riley Hospital for Children at Indiana University Health, Indianapolis, IN, USA and [2]Department of Pediatrics, Division of Cardiology, Indiana University School of Medicine, Riley Hospital for Children at Indiana University Health, Indianapolis, IN, USA

Original Article

Cite this article: Kaipa S, Yabrodi M, Benneyworth BD, Ebenroth ES, and Mastropietro CW (2021) Analysis of factors associated with prolonged post-operative course after surgical repair of aortic coarctation. *Cardiology in the Young* **31**: 191–198. doi: 10.1017/S1047951120003637

Received: 16 April 2020
Revised: 21 September 2020
Accepted: 4 October 2020
First published online: 3 November 2020

Keywords:
Aortic coarctation; enteral feeding; infant; newborn; length of stay; post-operative period; risk factors

Author for correspondence:
Santosh Kaipa, MD, MS, Department of Pediatrics, Division of Critical Care Medicine, Indiana University School of Medicine, Riley Hospital for Children at Indiana University Health, 705 Riley Hospital Drive, Phase 2, Rm 4911A, Indianapolis, IN 46202, USA.
Tel: +1 317 944 1610; Fax: +1 317 944 3442.
E-mail: santoshkaipa@gmail.com

The results in this manuscript were presented in abstract form at Neoheart 2018, the annual meeting of the Neonatal Heart Society, Fort Worth, TX, March, 2018.

Abstract

Objective: We sought to describe patient characteristics associated with prolonged post-operative length of stay in a contemporary cohort of infants who underwent isolated repair of aortic coarctation. *Methods:* We reviewed patients less than 1 year of age who underwent isolated repair of aortic coarctation at our institution from 2009 to 2016. Prolonged post-operative length of stay was defined as length of stay within the upper tertile for the cohort. Bivariate and multi-variable analyses were performed to determine independent risk factors for prolonged length of stay. *Results:* We reviewed 95 consecutive patients who underwent isolated repair of aortic coarctation, of whom 71 were neonates at the time of diagnosis. The median post-operative length of stay was 6.5 days. The upper tertile for post-operative length of stay was greater than 10 days; 32 patients within this tertile and 1 patient who died at 8.5 days after surgery were analysed as having prolonged post-operative length of stay. In a multi-variable analysis, pre-maturity (odds ratio: 3.5, 95% confidence interval: 1.2, 10.7), genetic anomalies (odds ratio: 4.7, 95% confidence interval: 1.2, 18), absence of pre-operative oral feeding (odds ratio: 7.4, 95% confidence interval: 2.4, 22.3), and 12-hour vasoactive-ventilation-renal score greater than 25 (odds ratio: 7.4, 95% confidence interval: 1.9, 29) were independently associated with prolonged length of stay. *Conclusions:* In neonates and infants who underwent isolated repair of aortic coarctation, pre-maturity, genetic anomalies, lack of pre-operative oral feedings, and 12-hour vasoactive-ventilation-renal score more than 25 were independent risk factors for prolonged post-operative length of stay. Further study on the relationship between pre-operative oral feedings and post-operative length of stay should be pursued.

Coarctation of the aorta is a low-complexity congenital heart lesion first described in 1760 by Morgagni. It is one of the most common forms of congenital heart disease accounting for 5–8% of congenital heart defects.[1–3] The first surgical repair of aortic coarctation was described in a 11-year-old child in 1944.[4] By the 1950s, surgical repair was being extended to infants and, with the introduction of prostaglandin infusions in the mid-1970s, it became possible to stabilise critically ill neonates pre-operatively and offer surgical repair of aortic coarctation to these fragile patients.[3] Over the years, with advances in surgical techniques and post-operative management, mortality following repair of aortic coarctation has been minimised, even in the smallest of neonates and infants. Indeed, a recent study from the Society of Thoracic Surgeons Congenital Heart Surgery Database (STS-CHSD) reported an operative mortality rate of 1%.[5] Complications including cardiac arrest, unplanned reoperation, chylothorax, and pleural effusion were also uncommon.[5] This study and others, however, have reported significant variation in the post-operative length of stay following surgical repair of aortic coarctation.[5,6] For example, the mean duration of hospital length of stay in the study from the STS-CHSD for patients with isolated aortic coarctation was 9.7 ± 16.2 days.[5] The wide standard deviation observed in this study suggests that, despite the low complexity of their congenital heart lesion and relatively low incidence of complications, some children undergoing repair of aortic coarctation require prolonged recovery periods.[5,6]

To our knowledge, risk factors for prolonged recovery after isolated repair of aortic coarctation have not been well-described in contemporary cardiac surgical populations. We sought to describe the variation in the post-operative length of stay in neonates and infants undergoing surgical repair of isolated repair of coarctation of the aorta at our institution. We also aimed to describe the characteristics of patients with prolonged post-operative courses following isolated repair of aortic coarctation and identify risk factors for its occurrence.

CAMBRIDGE UNIVERSITY PRESS

https://doi.org/10.1017/S1047951120003637 Published online by Cambridge University Press

Materials and methods

Patients

We conducted a single-institution retrospective analysis of all neonates and infants less than 365 days of age who underwent isolated repair of aortic coarctation at our institution between 1 January, 2009 and 31 December, 2016. The study was approved by the Institutional Review Boards at Indiana University School of Medicine and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Due to the retrospective nature of the data, the need for informed consent was waived. Patients older than 365 days or patients who underwent concomitant procedures (e.g. repair of the ventricular septal defect, pulmonary artery banding, etc.) were excluded.

Data collection

Demographic information and pre-operative characteristics were manually collected from the electronic medical record for all patients. Specifically, we recorded gestational age and birth weight; age and weight at surgery; weight for age z score at surgery; the presence of genetic or non-cardiac anatomic anomalies; the need for prostaglandin infusion; timing and disease severity upon presentation; the need for mechanical ventilation; and pre-operative feeding history. Pre-operative echocardiographic data recorded included pressure gradient across the coarctation, left ventricular function, left ventricle end-diastolic diameter z score based on Boston criteria, and any associated cardiac defects.[7] Operative data collected included the type of surgical repair; surgical approach (i.e. lateral thoracotomy versus sternotomy); duration of aortic cross-clamping; and need of blood products transfusions. Post-operative variables collected included the use and duration of vasoactive medications; use of antihypertensive medications; left ventricular function and residual aortic arch gradient on post-operative echocardiogram; time to initiation of feeds; time to achieve goal caloric intake; and post-operative complications such as post-coarctectomy hypertension, feeding dysfunction, pneumothorax, symptomatic vocal cord dysfunction, and diaphragmatic paralysis. Other post-operative outcomes recorded included the duration of mechanical ventilation, duration of post-operative length of stay, and mortality.

Definitions

Neonatal age was defined as less than or equal to 30 days at the time of diagnosis. Pre-maturity was defined as less than 37 weeks gestation. Pre-operative mechanical ventilation was defined as invasive mechanical ventilation at any point before surgery. Pre-operative shock was defined as pH less than 7.2 or lactate greater than 4 mg/dl, to be consistent with the definitions utilised by the STS-CHSD.[8] The absence of pre-operative oral feeding was defined as patients who were never orally fed from the time of birth to their surgical correction or patients who did not tolerate attempts to orally feed (i.e. one or two attempts to orally feed but failed due to vomiting or abdominal distension). Patients who never received enteral feeding or exclusively fed by nasogastric tube prior to the surgery are included in this definition. Post-coarctectomy hypertension was defined as the use of titratable antihypertensive infusions in the immediate post-operative period. Pre-operative and post-operative feeding including the timing of initiation of enteral and oral feedings during the study period was not protocolised but rather at the discretion of the primary care team. Post-operative feeding difficulty was defined as the need to hold enteral feedings for at least 1 hour for vomiting or abdominal distention. Goal caloric intake was defined as 120 kcal/kg/day based on our nutritionist recommendations. The primary outcome variable – prolonged post-operative hospital length of stay – was defined as length of stay within the upper tertile for the study population or mortality prior to hospital discharge. Notably, we opted to focus our study on hospital length of stay rather than ICU length of stay, as the morbidity experienced by children recovering from cardiac surgery and the multi-disciplinary resources required to manage these patients extend beyond the borders of the ICU.

We also calculated the vasoactive-ventilation-renal score (VVR) for all patients at 12- hour post-surgery. The vasoactive-ventilation-renal score is a validated marker of post-operative disease severity that is calculated by the below formula[9–12]:

$$\mathrm{VVR} = \mathrm{VIS} + \mathrm{VI} + (\Delta\mathrm{Cr} \times 10)$$

The vasoactive inotrope score (VIS) is calculated using the formula described by Gaies et al: VIS = dopamine dose (mcg/kg/minute) + dobutamine dose (mcg/kg/minute) + 100 × epinephrine dose (mcg/kg/minute) + 10 × milrinone dose (mcg/kg/minute) + 10,000 × vasopressin dose (U/kg/minute) + 100 × norepinephrine dose (mcg/kg/minute).[13] For patients on no vasoactive support at the 12-hour post-operatively, the VIS is 0. The ventilation index was calculated using the post-operative arterial blood gas measurement closest to 12-hour post-arrival to the cardiac intensive care unit as follows: $\mathrm{VI} = \mathrm{RR} \times (\mathrm{PIP} - \mathrm{PEEP}) \times \mathrm{PaCO_2}/1000$ where RR is a respiratory rate, PIP is peak inspiratory pressure, PEEP is positive end-expiratory pressure, and $\mathrm{PaCO_2}$ is the partial pressure of carbon dioxide. For patients not on mechanical ventilation at the 12-hour interval, the VI is 0. Lastly, ΔCr was calculated by subtracting baseline pre-operative serum creatinine from the 12-hour post-operative serum creatinine measurement (i.e. value obtained closest to 12-hour post-operatively but not after this time point). For patients in whom post-operative serum creatinine measurements were less than baseline, ΔCr is 0.

Statistical analysis

All statistical analysis was performed using STATA® version 15. Descriptive statistics were used to represent the study population. Data are provided as medians with 25 and 75% for continuous variables and absolute counts with percentages for categorical variables. Bivariate analysis comparing patients with prolonged post-operative length of stay and without prolonged post-operative length of stay was performed using Wilcoxon rank-sum tests, chi-square tests, or Fisher's exact tests for individual variables as appropriate. Variables with p values <0.2 on bivariate analysis were considered for the multi-variable model. Variables with p values <0.05 on multi-variable analysis were identified as independent risk factors for prolonged post-operative length of stay after isolated repair of coarctation of the aorta. This analysis was then repeated on the subset of patients who underwent surgery as neonates. Results of the multi-variable model are provided as odds ratios (OR) with 95% confidence intervals (CI).

Results

We reviewed 95 consecutive patients less than 1 year of age who underwent isolated repair of coarctation of the aorta during the study period, of whom 64 (67%) were neonates (less than or equal

https://doi.org/10.1017/S1047951120003637 Published online by Cambridge University Press

Table 1. Bivariate comparison of pre-operative and intra-operative characteristics of patients with and without prolonged length of stay (LOS) after repair of aortic coarctation

Variable	All patients (n = 95)	LOS ≤ 10 days (n = 62)	LOS > 10 days (n = 33)	p values
Age at surgery (days)	13 (8, 41)	13 (8, 38)	14 (7, 41)	0.71
Neonate at diagnosis (≤30 days)	71 (75%)	47 (76%)	24 (73%)	0.74
Pre-maturity (<37 weeks)	29 (31%)	13 (21%)	16 (49%)	0.006
Female sex	41 (43%)	27 (44%)	14 (43%)	0.92
Chromosomal anomaly	16 (17%)	5 (8%)	11 (33%)	0.002
Non-cardiac anatomic anomaly	31 (33%)	13 (21%)	18 (55%)	0.001
Pre-operative echocardiogram data				
LV ejection fraction (%)	64 (49, 70)	63 (45, 69)	66 (58, 71)	0.38
LV end-diastolic diameter z score	−0.4 (−1.5, 0.8)	−0.5 (−1.4, 0.4)	−0.4 (−1.8, 1.5)	0.90
Mitral valve disease	40 (42%)	23 (37%)	17 (52%)	0.18
Aortic stenosis	11 (12%)	7 (11%)	4 (12%)	1.0
PFO/ASD	76 (80%)	48 (77%)	28 (85%)	0.43
Ventricular septal defect	16 (17%)	7 (11%)	9 (27%)	0.047
Aortic arch hypoplasia	22 (23%)	14 (23%)	8 (24%)	0.86
Ductal-dependent systemic blood flow	49 (52%)	31 (50%)	18 (55%)	0.67
Pre-operative invasive ventilation	38 (40%)	21 (34%)	17 (52%)	0.10
Pre-operative shock	13 (14%)	11 (18%)	2 (6%)	0.21
Pre-operative oral feeding	64 (67%)	52 (84%)	12 (36%)	<0.001
Aortic cross-clamp duration (minutes)	15 (13, 1)	15 (13, 19)	16 (14, 18)	0.74
Intra-operative transfusion	45 (47%)	29 (47%)	16 (48%)	0.87

Continuous data presented as median (25th%, 75th%); categorical data presented as absolute counts, n (%)
Abbreviations: ASD = atrial septal defect; LV = left ventricle; PFO = patent foramen ovale

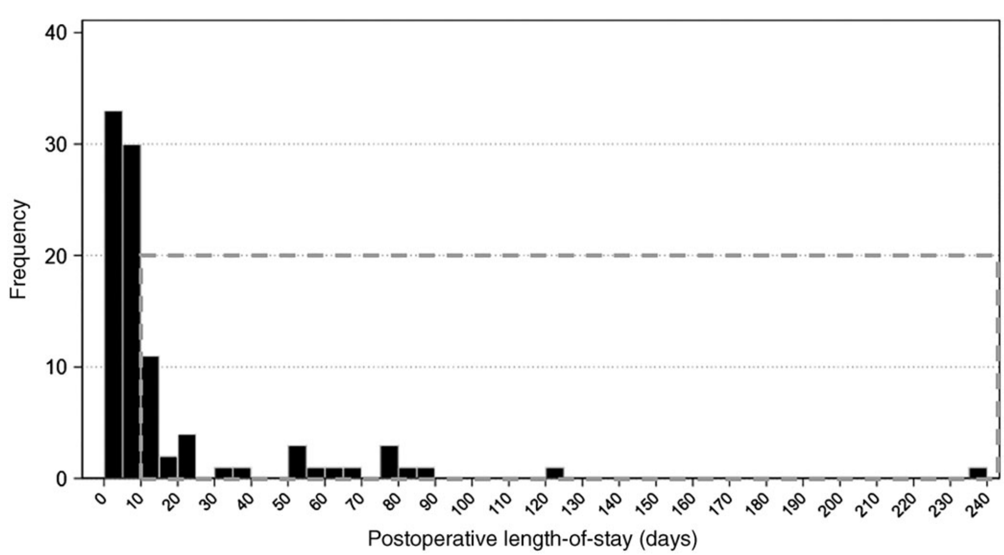

Figure 1. Post-coarctectomy study.

to 30 days old at the time of surgery). Data summarising the patient population are provided in Table 1. The median age at surgery was 13 days (25%, 75%: 8, 41). Notably, 29 patients (31%) were born pre-maturely, 16 patients (17%) had genetic abnormalities, and 31 patients (33%) had non-cardiac anatomic abnormalities. Only six patients were diagnosed prenatally and 49 patients (52%) had ductal-dependent systemic blood flow requiring prostaglandin infusion pre-operatively. Despite the implementation of routine pulse oximetry screening to identify critical congenital heart disease in newborns in 2012, only four patients in our cohort were identified after abnormal pulse oximetry screening.

All the patients in our cohort underwent lateral thoracotomy with extended end-to-end anastomosis. The median post-operative length of stay was 6.5 days. The distribution of post-operative length of stay is provided in Fig 1. Prolonged post-operative length of stay, defined as greater than 10 days (i.e. upper tertile), occurred in 32 children,

https://doi.org/10.1017/S1047951120003637 Published online by Cambridge University Press

Table 2. Specific genetic diagnoses and organ system anomalies in patients who underwent isolated repair of aortic coarctation

Variable	All patients (n = 95)	LOS ≤ 10 days (n = 62)	LOS > 10 days (n = 33)
Genetic/chromosomal diagnosis	16 (17%)	5 (8%)	11 (33%)
Turner's syndrome	3	2	1
Down's syndrome	2	0	2
Trisomy 18	1	0	1
Cornelia de Lange syndrome	1	0	1
Coffin–Siris syndrome	1	0	1
Williams syndrome	1	1	0
Other	7	2	5
None detected	12	9	3
Not tested	67	48	19
Non-cardiac anatomic anomalies	31 (33%)	13 (21%)	18 (55%)
Genitourinary	6	4	2
Neurological	4	2	2
Airway	3	0	3
Lung/diaphragm	4	1	3
Gastrointestinal	3	1	2
Haemangioma/ lymphatic	3	3	0
Limb/skeletal	2	2	0
Multiple organ system anomalies	6	0	6

and one child who died prior to 10 days post-operatively was also included in this sub-group. Bivariate comparison of pre-operative and intra-operative characteristics of the patients with and without prolonged length of stay is described in Table 1. We found that patients with prolonged length of stay were significantly more likely to be born pre-maturely and have genetic or non-cardiac anomalies. More granular data describing the genetic diagnoses and non-cardiac anomalies identified are provided in Table 2. Patients with prolonged length of stay were also less likely to have fed orally pre-operatively and more likely to have ventricular septal defects. Other pre-operative echocardiographic findings including cardiac function and the severity of the coarctation (as defined by the measured pressure gradient across the lesion) were not statistically different between patients with and without prolonged length of stay, nor were the proportion of patients who had ductal dependent systemic blood flow or presented clinically in shock.

Bivariate comparison of post-operative characteristics and outcomes of patients with and without prolonged post-operative hospital length of stay is described in Table 3. Patients with prolonged length of stay had significantly higher 12-hour vasoactive-ventilation-renal scores and were more likely to undergo surgical or catheterisation re-intervention prior to discharge, whereas the incidence of post-coarctectomy hypertension was significantly greater in patients without prolonged length of stay. Additionally, time to initiation of enteral feedings and time to goal caloric intake was significantly longer and post-operative feeding difficulties were significantly more common in patients with prolonged length of stay. The occurrence rates of other post-operative complications were low, with only three patients in the study suffering a pneumothorax, three patients developing necrotising enterocolitis, and two patients diagnosed with vocal cord dysfunction post-operatively. None of the patients in the cohort developed chylothorax or surgical site infections.

Post-operative echocardiograms were performed in 76 patients (80%). In this subset of patients, residual arch gradient (measured in all 76 patients) and left ventricular ejection fraction (measured in 73 of 76 patients) were not significantly different between patients with prolonged length of stay as compared to the rest of the cohort. For the 19 patients without post-operative echocardiograms, upper and lower extremity blood pressure differences were reviewed and were 10 mmHg or less in all patients. On the other hand, while we found no statistical difference in residual aortic arch gradient between the two comparison groups, all six patients with residual arch gradients greater than 30 mmHg (with a range from 31 to 50) had prolonged length of stay. Five of these six patients underwent catheter or surgical reintervention to address their residual lesion prior to discharge: four patients underwent balloon angioplasty and one patient underwent unsuccessful balloon angioplasty followed by surgical arch reconstruction.

There were two post-operative deaths. One patient, born small for gestational age (1.8 kg) at 33 weeks, was taken to the cardiac catherisation suite on post-operative day 8 to address residual aortic valvular stenosis and suffered a cardiac arrest during induction of anaesthesia, with no return of spontaneous circulation. The other patient died on post-operative day 55 secondary to complications arising from Trisomy 18 and multiple additional comorbidities.

The results of our multi-variable analyses are provided in Table 4. Pre-maturity, presence of genetic anomalies, absence of pre-operative oral feedings, and 12-hour VVR score greater than 25 were independently associated with prolonged length of stay. These variables remained independently associated with prolonged length of stay when only patients who were diagnosed with critical coarctation of the aorta as neonates were considered. Notable variables that were not found to have an appreciable effect on the model included the presence of a ventricular septal defect, concomitant mitral valve disease, pre-operative mechanical ventilation, and post-coarctectomy hypertension.

Due to the independent relationship identified between the absence of pre-operative oral feedings and prolonged length of stay, we decided *post-hoc*, to look more closely at the 31 patients who were not fed orally pre-operatively (21 with prolonged length of stay, 10 without prolonged length of stay). Eight of these patients could not be fed orally due to their dependence on mechanical ventilation. In another four patients, oral feeds were attempted but not tolerated. For the remaining 19 patients who were not fed orally pre-operatively, no clear discernible reason for the absence of pre-operatively oral feedings could be gleaned from the medical record. We also compared patients who were not fed orally pre-operatively to those who were successfully fed pre-operatively (n = 64), the results of which are provided in Table 5. Patients who were not fed orally pre-operatively were more likely to have non-cardiac anomalies and were more likely to have required mechanical ventilation at some point pre-operatively but were not statistically different in terms of age at diagnosis or surgery, were more likely to require

Table 3. Bivariate comparison of post-operative characteristics and outcomes of patients with and without prolonged length of stay (LOS) after repair of aortic coarctation

Variable	All patients (n = 95)	LOS ≤ 10 days (n = 62)	LOS > 10 days (n = 33)	p values
Need for post-operative inotropic support	28 (29%)	16 (48%)	12 (36%)	0.28
12-hour VVR	13 (12, 21)	8 (0.2, 16)	20 (11, 28)	<0.001
Post-coarctectomy hypertension	17 (18%)	15 (24%)	2 (6%)	0.046
Time to post-operative enteral feedings (hours)	41 (22, 62)	29 (22, 51)	51 (39, 74)	0.004
Time to achieve goal caloric intake (hours)*	60 (28, 126)	42 (22, 68)	159 (85, 264)	<0.001
Post-operative feeding difficulties	37 (39%)	10 (16%)	27 (82%)	<0.001
Post-operative echocardiogram data				
LV ejection fraction (%)**	67 (60, 72)	67 (62, 72)	65 (57, 75)	0.17
Residual aortic arch gradient***	10 (0, 16)	9 (0, 15)	10 (0, 18)	0.94
Residual aortic arch gradient > 30 mmHg***	6 (8%)	0 (0%)	6 (20%)	0.003
Need for catheterization intervention	6 (6%)	0 (0%)	6 (18%)	0.001
Balloon angioplasty of aortic arch	5	0	5	
Balloon angioplasty of aortic valve	1	0	1	
Need for surgical intervention	5 (5%)	1 (2%)	4 (12%)	0.048
ASD/VSD closure	2	0	2	
Mitral valvotomy	1	0	1	
Aortic arch reconstruction	1	0	1	
Drainage of surgical wound haematoma	1	1	0	
Duration of mechanical ventilation (hours)	20 (5, 43)	18 (4, 23)	61 (21, 117)	<0.001
Duration of ICU stay (days)	2.9 (2.0, 6.5)	2.1 (1.9, 3.1)	13.0 (4.1, 55)	<0.001

Continuous data presented as median (25th%, 75th%); categorical data presented as absolute counts, n (%)
Abbreviations: ASD = atrial septal defect; VSD = ventricular septal defect; VVR = vasoactive-ventilation-renal score
*Available for 94 patients; time to goal caloric intake could not be determined for 1 patient without prolonged LOS
**Available for 73 patients, 45 without prolonged LOS, and 28 with prolonged LOS
***Available for 76 patients, 46 without prolonged LOS, and 30 with prolonged LOS

Table 4. Multi-variable analysis of risk factors for prolonged length of stay after repair of aortic coarctation

All patients (n = 95)	OR	95% CI
Pre-maturity (<37 weeks)	3.2	1.04–9.8
Genetic anomaly	4.4	1.1–17.3
No pre-operative oral feedings	9.0	2.9–28.0
12-hour VVR > 25	7.0	1.8–28.0
Neonates (n = 71)	OR	95% CI
Pre-maturity (<37 weeks)	5.1	1.4–18.4
Genetic anomaly	6.5	1.2–35.5
No pre-operative oral feedings	5.2	1.5–18.7
12-hour VVR > 25	5.9	1.3–26.7

Abbreviations: CI = confidence interval; OR = odds ratio; VVR = vasoactive-ventilation-renal score

prostaglandin infusion, and were not more likely to have had a pre-operative shock or left ventricular dysfunction. Post-operatively, patients who did not feed orally pre-operatively were more likely to have received their enteral nutrition initially via a nasogastric tube rather than orally and a required significantly longer time to tolerate goal caloric intake.

Discussion

In the current era, as outcomes from surgery for congenital heart disease continue to improve and operative mortality decreases, especially for patients with low-complexity lesions such as coarctation of the aorta, many have begun to focus on the goal optimisation of resource utilisation without negatively impacting the quality of care. Accordingly, resource utilisation is proportional to hospital length of stay, with patients with prolonged hospital courses often requiring the most resources at considerable costs. Hence, efforts to identify and understand factors associated with prolonged post-operative length of stay for cardiac surgical procedures are of paramount importance, as these factors could be the focus of quality improvement efforts aimed at reducing resource utilisation and costs associated with these prolonged courses. To this end, we identified pre-maturity, genetic anomalies, absence of pre-operative oral feedings, and 12-hour VVR score as predictive of prolonged post-operative length of stay following isolated repair of coarctation of the aorta.

Pre-maturity and genetic anomalies as risk factors for post-operative morbidity and mortality after surgery for congenital heart disease have been well-described.[14–19] For the majority of these patients, their post-operative courses were likely influenced, to some degree, by issues related to underlying co-morbidities such as chronic lung disease, airway or gastrointestinal anomalies, and feeding dysfunction common to these children. These risk factors

https://doi.org/10.1017/S1047951120003637 Published online by Cambridge University Press

are largely unmodifiable and thus relatively unhelpful to physicians aiming to reduce prolonged length of stay in this patient population. Physicians however should be aware that patients with congenital heart disease and underlying genetic or non-cardiac abnormalities can require prolonged hospitalisation, regardless of the complexity of the underlying cardiac lesion.

We identified vasoactive-ventilation-renal score greater than 25 at 12-hour post-operatively was independently associated with prolonged length of stay. This finding is consistent with prior studies.[10–12] Though not an easily modifiable risk factor, the vasoactive-ventilation-renal score can function as a marker of disease burden and provide families realistic expectations of their child's post-operative course and assist in resource allocation. More importantly, by including the vasoactive-ventilation-renal score in our multi-variable model, we can assert that our findings regarding pre-maturity, genetic anomalies, and absence of pre-operative oral feedings and their association with prolonged length of stay are independent of early post-operative illness severity.

We also found that the absence of pre-operative oral feedings, independent of underlying pre-maturity, genetic or non-cardiac anomalies, and post-operative illness severity, as a risk factor for prolonged length of stay following coarctectomy, which may be modifiable. We also noted that patients with prolonged length of stay required more time to achieve their goal caloric intake and more commonly experienced post-operative feeding dysfunction while other commonly described complications of coarctectomy (e.g. hypertension, vocal cord paralysis, and pneumothorax) were not associated with prolonged recovery. Though studies have demonstrated that enteral feeding prior to surgery can have beneficial effects in children undergoing cardiac surgery including a shorter duration of mechanical ventilation and decreased length of stay,[20–22] data describing the impact of pre-operative oral feedings on post-operative outcome are sparse. Notably, one single-centre study demonstrated that the implementation of standardised peri-operative feeding guidelines can help to limit practice variations and reduce length of stay in neonates recovering from surgery for congenital heart disease.[23] Despite these data, feeding management practices are highly variable across centres, with little consensus, even among physicians within each centre, with no guidelines available to inform practice.[24] A recent report from the Pediatric Cardiac Critical Care Consortium showed that only half of neonates who underwent surgery received pre-operative enteral feeds, varying between 29 and 79% in the eight centres involved in the study.[25] The proportion of children fed orally prior to surgery for congenital heart disease is less clear. While the frequency of pre-operative oral feeds was reported to be 52% of neonates with congenital heart disease in one single-centre study, multi-centre data, to our knowledge, have not been published.[26] In our cohort, we observed a striking relationship between the lack of oral feedings pre-operatively and prolonged recovery. Indeed, the odds of a prolonged length of stay in patients who were not fed orally before surgery were nine times that of children who were allowed to orally feed pre-operatively. We also noted significant relationships between the absence of oral feedings and post-operative feeding difficulties. Further, in the majority of these patients, the clinical indication(s) for not permitting oral feeding was not clearly documented in the medical record other than physician discretion. Children who were not fed orally pre-operatively were similar in age at diagnosis and surgery when compared to those who were able to feed orally pre-operatively and were not more likely to have had pre-operative hemodynamic instability or be dependent on prostaglandin infusions.

While it is possible that some infants who were not fed orally pre-operatively could have done so if given the opportunity, we cannot assert, based on our data, that the absence of pre-operative feeding directly contributed to the protracted post-operative courses experienced by some of our patients, It is possible, however, that clinicians are likely less cautious in initiating post-operative enteral feeding in neonates who were orally feeding prior to surgery when compared to those who were not. Indeed, children who fed orally pre-operatively received post-operative enteral nutrition sooner and the initial post-operative enteral feeding modality was oral in more than half of these patients, in contrast only 26% of children who did not feed orally post-operatively. Neonates who fed orally pre-operatively could also be quicker to regain oromotor abilities after extubation from mechanical ventilation, leading to faster attainment of their goal feeding and expedition of discharge. If these hypotheses have merit, quality improvement initiatives aimed at encouraging oral feedings in children waiting for cardiac surgery, which would be logistically simple, could potentially reduce post-operative length of stay.

Lastly, while the median residual gradient as measured on post-operative echocardiogram was not significantly different between the two comparison groups, all patients with residual aortic arch gradients greater than 30 mmHg after surgery had prolonged length of stay, with five of these patients requiring surgical or cardiac catheterisation intervention prior to discharge. This finding is not surprising, considering that current literature recommends surgical repair of coarctation of the aorta when the peak-to-peak gradient is greater than 20 mmHg.[3] Hence, parents of children with residual coarctation of 30 mmHg or more after surgical repair should be prepared for the possibility of a protracted post-operative course, with the likely need for intervention prior to hospital discharge.

Our study has several limitations. The study design was retrospective in nature, and thus, for data from some variables that could have proved important were not available. For example, post-operative echocardiograms were not performed on all patients, limiting our ability to fully assess the relationship between post-operative echocardiographic data and outcome. Our study population was also relatively small and single centre in nature, potentially limiting its generalisability. The small size of the patient population also limited the number of variables that could reliably be included in the multi-variable model; a larger study, which would have to be multi-centre in nature, is needed to confirm our results. We also did not calculate the power required to calculate the effect of the variables on the outcomes. Importantly, we are not advocating for practice change based on our data but rather encouraging other institutions to pursue their own quality improvement initiatives, the design of which would be dictated by local practices, to determine if pre-operative oral feedings protocols can impact post-operative course. Lastly, we acknowledge that defining prolonged length of stay as the upper tertile for the cohort was somewhat arbitrary, though our definition may be justified by Fig 1, in which the sub-group designated as prolonged length of stay represents the tail of our skewed outcome measure.

Conclusions

In neonates and infants who underwent isolated repair of aortic coarctation, pre-maturity, genetic anomalies, lack of pre-operative oral feedings, and 12-hour vasoactive-ventilation-renal score more than 25 were independent risk factors for prolonged post-operative length of stay. Further research and quality improvement

https://doi.org/10.1017/S1047951120003637 Published online by Cambridge University Press

Table 5. Bivariate comparison of characteristics of patients who did and did not feed orally pre-operatively prior to repair of aortic coarctation

Variable	No pre-operative oral feeds (n = 31)	Pre-operative oral feeds (n = 64)	p values
Age at diagnosis (days)	7 (1, 28)	11 (5, 33)	0.10
Age at surgery (days)	13 (6, 39)	13 (9, 45)	0.21
Pre-maturity (<37 weeks)	13 (42%)	16 (25%)	0.09
Chromosomal anomaly	8 (26%)	8 (13%)	0.10
Non-cardiac anomalies	17 (55%)	14 (22%)	0.001
Airway	2	1	
Lung/diaphragm	3	1	
Gastrointestinal	3	0	
Neurological	1	3	
Other single-organ anomaly	4	7	
Multi-organ anomaly	4	2	
Prostaglandin E_1-dependent	22 (71%)	33 (52%)	0.07
Pre-operative shock	1 (3%)	12 (19%)	0.05
Pre-operative LV dysfunction	7 (23%)	25 (39%)	0.11
Pre-operative inotropic support	2 (6%)	12 (19%)	0.14
Pre-operative ventilation, any	17 (55%)	21 (33%)	0.04
Pre-operative ventilation with 24 hours of surgery	11 (32%)	15 (23%)	0.22
Time to post-operative enteral feeding (hours)	45 (25, 55)	35 (22, 63)	0.40
Initial post-operative feeding method			0.006
Nasogastric tube only	20 (65%)	20 (31%)	
Oral and nasogastric tube	3 (10%)	8 (13%)	
Oral only	8 (26%)	36 (56%)	
Post-operative feeding difficulties	21 (68%)	16 (25%)	<0.001
Time to achieve goal caloric intake (hours)*	99 (55, 218)	48 (27, 91)	0.003
Post-operative NEC	1 (3%)	2 (3%)	1.00

Continuous data presented as median (25%, 75%), categorical data presented absolute counts (n) with percentages
Abbreviations: LV = left ventricle; NEC = necrotizing enterocolitis
*Time to goal caloric intake could not be determined for one patient who tolerated oral feeds pre-operatively

initiatives focused on the relationship between pre-operative oral feedings and post-operative length of stay should be pursued.

Acknowledgements. None.

Financial support. This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Conflicts of interest. None.

References

1. Zani A, Cozzi DA. Giovanni Battista Morgagni and his contribution to pediatric surgery. J Pediatr Surg 2008; 43: 729–733.
2. Crafoord C, Nylin G. Congenital coarctation of the aorta and its surgical treatment. J Thoracic Surg 1945; 14: 347–361.
3. Torok RD, Campbell MJ, Fleming GA, Kevin DH. Coarctation of the aorta: management from infancy to adulthood. World J Cardiol 2015; 7: 765–775.
4. Kvitting JE, Olin, CL. Clarence Crafoord: a giant in cardiothoracic surgery, the first to repair aortic coarctation. Ann Thorac Surg 2009; 87: 342–346.
5. Ungerleider RM, Pasquali SK, Welke KF, et al. Contemporary patterns of surgery and outcomes for aortic coarctation: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. J Thorac Cardiovasc Surg 2013; 145:150–158.
6. Mery CM, Guzmán-Pruneda FA, Trost JG Jr, et al. Contemporary results of aortic coarctation repair through left thoracotomy. Ann Thorac Surg 2015; 100: 1039–1046.
7. Boston Children's Hospital Z-Score Calculator. http://zscore.chboston.org/
8. Society of Thoracic Surgeons 2015. Congenital Heart Surgery Database Data Specifications Version 3.3. https://www.sts.org/sites/default/files/documents/CongenitalDataSpecsV3_3_Updated.pdf
9. https://medicine.iu.edu/departments/pediatrics/clinical-care/vasoactive-ventilation-renal-score-calculator
10. Scherer B, Moser EA, Brown JW, Rodefeld MD, Turrentine MW, Mastropietro CM. Vasoactive-ventilation renal score reliably predicts hospital length of stay after surgery for congenital heart disease. J Thorac Cardiovasc Surg 2016; 152:14231429.
11. Miletic, KG, Delius RE, Walters, HL III, Mastropietro CW. Prospective validation of a novel vasoactive-ventilation-renal score as a predictor of outcomes after pediatric cardiac surgery. Ann Thorac Surg 2016; 101: 1558–1563
12. Cashen K, Costello JM, Grimaldi LM, et al. Multicenter validation of the vasoactive-ventilation-renal score as a predictor of prolonged mechanical ventilation after neonatal cardiac surgery. Pediatr Crit Care Med 2018; 19: 1015–1023.

https://doi.org/10.1017/S1047951120003637 Published online by Cambridge University Press

13. Gaies MG, Gurney JG, Yen AH, et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. Pediatr Crit Care Med 2010; 11: 234–238.
14. Costello JM, Pasquali SK, Jacobs JP, et al. Gestational age at birth and outcomes after neonatal cardiac surgery: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. Circulation 2014; 129: 2511–2517.
15. Steurer MA, Baer RJ, Keller RL, et al. Gestational age and outcomes in critical congenital heart disease. Pediatrics 2017; 140: e20170999.
16. Cnota JF, Gupta R, Michelfelder EC, Ittenbach RF. Congenital heart disease infant death rates decrease as gestational age advances from 34 to 40 weeks. J Pediatr 2011; 159: 761–765.
17. Anderson BR, Stevens KN, Nicolson SC, et al. Contemporary outcomes of surgical ventricular septal defect closure. J Thorac Cardiovasc Surg 2013; 145: 641–647.
18. Schipper M, Slieker MG, Schoof PH, Breur JM. Surgical repair of ventricular septal defect; contemporary results and risk factors for a complicated course. Pediatr Cardiol 2017; 38: 264–270.
19. Simsic JM, Coleman K, Maher KO, Cuadrado A, Kirshbom PM. Do neonates with congenital heart disease and genetic abnormalities have increased mortality and morbidity. Congenit Heart Dis 2009; 4: 160–165.
20. Gillespie M, Kuijpers M, Van Rossem M, et al. Determinants of intensive care unit length of stay for infants undergoing cardiac surgery. Congenit Heart Dis 2006; 1: 152–160.
21. Iliopoulos I, Burke R, Hannan R, et al. Preoperative intubation and lack of enteral nutrition are associated with prolonged stay after arterial switch operation. Pediatr Cardiol 2016; 37: 1078–1084.
22. Scahill CJ, Graham EM, Atz AM, Bradley SM, Kavarana MN, Zyblewski SC. Preoperative feeding and necrotizing enterocolitis: is the fear justified? World J Pediatr Congenit Heart Surg 2017 8: 62–68.
23. Simsic JM, Carpentino KR, Kirchner K, et al. Reducing variation in feeding newborns with congenital heart disease. Congenit Heart Dis 2017; 12: 275–281.
24. Howley LW, Kaufman J, Wymore E, et al. Enteral feeding in neonates with prostaglandin-dependent congenital heart disease: inter-national survey on current trends and variations in practice. Cardiol Young 2012; 22: 121–127.
25. Alten JA, Rhodes LA, Tabbutt S, et al. Perioperative feeding management of neonates with CHD: analysis of the Pediatric Cardiac Critical Care Consortium (PC^4) Registry. Cardiol Young 2015; 25: 1593–1601.
26. Sables-Baus S, Kaufman J, Cook P, da Cruz EM. Oral feeding outcomes in neonates with congenital cardiac disease undergoing cardiac surgery. Cardiol Young 2012; 22: 42–48.