Pediatr Cardiol (2015) 36:489–497
DOI 10.1007/s00246-014-1038-8

ORIGINAL ARTICLE

Repair of Anomalous Left Coronary Artery From the Pulmonary Artery in the Modern Era: Preoperative Predictors of Immediate Postoperative Outcomes and Long Term Cardiac Follow-up

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Received: 20 June 2014 / Accepted: 27 September 2014 / Published online: 10 October 2014

Abstract Little is known about preoperative factors affecting postoperative morbidity following anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) repair. This study aimed at identifying predictors of postoperative outcomes, including mortality and left ventricle (LV) normalization. A retrospective, single institution review was conducted on forty-four ALCAPA repairs from April 1991 to November 2012. Preoperative clinical data and echocardiograms were analyzed. Postoperative outcomes included duration of intensive care supports and mortality. Time to normalization of LV end diastolic dimension (LVEDD) and function were assessed. Logistic regression and Cox proportional hazard analyses were used to correlate preoperative variables to postoperative outcomes. Forty-four patients underwent ALCAPA repair. No in-hospital or late mortality was observed. LVEDD, weight, and LV shortening fraction (SF) independently predicted duration of postoperative inotropic support. LVEDD and body surface area independently predicted the duration of postoperative intubation. For the infant majority, younger age predicted longer duration of postoperative intubation ($p = 0.048$) and LVEDD Z-score independently predicted duration of postoperative IV inotropic support ($p = 0.042$). LV function normalized in all patients for whom follow-up data was available. LVEDD Z-score independently predicted time to normalization of LV function ($p = 0.013$). ALCAPA repair in the current era has excellent outcomes, with no mortality in our cohort. Immediate postoperative morbidities are influenced by patient size, LVEDD, and preoperative SF. Outcomes of infantile ALCAPA are influenced by the degree of LV dilation. Time to normalization of LV function is related to LVEDD. Limitations included retrospective evaluation of LV function.

Electronic supplementary material The online version of this article (doi:10.1007/s00246-014-1038-8) contains supplementary material, which is available to authorized users.

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Keywords Anomalous coronary artery · Congenital heart disease · Pediatrics · Left ventricle

Abbreviations

ALCAPA	Anomalous origin of the left coronary artery from the pulmonary artery
LV	Left ventricle
BSA	Body surface area
MV	Mitral valve
EF	Ejection fraction
SF	Shortening fraction
LVEDD	Left ventricular end diastolic dimension
LVESD	Left ventricular end systolic dimension

Introduction

Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is a rare congenital anomaly occurring in 1 in 300,000 live births [3], yet it is one of the most common causes of pediatric myocardial ischemia and infarction. The infantile type is characterized by paucity of coronary collateralization, such that when pulmonary vascular resistance decreases, antegrade flow through the left coronary becomes retrograde, resulting in a drop in left coronary perfusion pressure. The resultant myocardial ischemia leads to progressive left ventricular (LV) dysfunction and dilation often exacerbated by developing mitral regurgitation, which culminates in heart failure. This is the typical way in which these patients present in the first few months of life. Presentation of ALCAPA may occur in an older age group, whose coronary collateralization have prevented significant ischemia and therefore present with often normal or near normal LV size and function.

Immediate surgical correction aimed at re-establishing a dual coronary system is the gold standard of care, and outcomes have been favorable in the current era of coronary reimplantation. It has been reported that LV function and end diastolic dimension normalize in the majority of patients within the first post-operative year [2, 7]. Additionally, many studies have examined the preoperative variables that predict postoperative mortality. Schwartz et al. found a high degree of mitral regurgitation at presentation was a significant risk factor for perioperative mortality while age, body surface area (BSA), and preoperative LV function and end diastolic dimension did not predict mortality [7]. In contrast, Lange, et al reported both preoperative age and LV function as predictors for 30-day postoperative mortality [4]. Higher perioperative mortality was associated with younger age at operation and ECG findings of extensive myocardial infarction in a study done by Sauer et al [6]. While postoperative mortality has been well described, little is known about which preoperative patient factors affect postoperative morbidity in the pediatric intensive care unit (ICU). This study aimed at identifying preoperative predictors of immediate postoperative outcomes, including mortality. Additionally, long-term follow-up of echocardiographic LV normalization and medication use was evaluated with potential predictors of duration of LV dysfunction analyzed.

Methods

Population

We performed a retrospective chart and echocardiographic review of all patients who underwent ALCAPA repair at our institution from April 1991 to November 2012. The patients with this procedure were selected from a surgical database maintained of all cardiothoracic surgeries at our institution since 1990. Patients were included if they underwent repair of a left coronary artery or one of its major branches arising from the main or branch pulmonary artery. Patients with other coronary artery anomalies, including anomalous right coronary artery from the pulmonary artery, coronary artery fistulae, and anomalous aortic origin of the coronary artery were excluded. Patients were then divided into an infant group (≤1 year) and non-infant group (>1 year) for further statistical analysis, with recognition that these were two clinically distinguishable groups of patients with ALCAPA. The study was approved by the Columbia University Medical Center Institutional Review Board (Protocol # IRB-AAAI7150).

Data Collection

Patient demographics, preoperative clinical data, and electrocardiograms were obtained from electronic medical records and archived paper charts. Demographic information including age, weight, and BSA were recorded. Preoperative intubation status, degree of intravenous inotropic support, and mechanical circulatory support status were recorded. Surgical data included the precise origin of the anomalous left coronary artery, whether simultaneous mitral valve (MV) repair or other repairs were undertaken, the technique of ALCAPA repair, cross-clamp and bypass time, and whether postoperative mechanical support or delayed sternal closure occurred. The use and duration of postoperative inotropes, the duration of intubation, length of ICU stay, length of total hospitalization, and mortality were determined. Preoperative electrocardiograms were evaluated for the presence and pattern of myocardial ischemia and infarct. Patterns of ischemia were defined as inferior, anterior, lateral, high lateral, anterolateral, and posterior based on well-recognized distribution of ST segment changes and Q waves [1]. ST changes were considered significant if they were greater than or equal to 1 millimeter in depression or elevation or if they were greater than or equal to 10 percent of the combined R and S wave amplitude. Q waves were considered significant for infarct if they were of duration greater than or equal to 20 milliseconds or of depth greater than or equal to 25 % of the R wave height. Preoperative echocardiograms were obtained and reviewed by a single reader (JW) on either VHS (for studies preceding the institution's echo server) or on digital echocardiogram server. Preoperative echocardiogram variables that were measured included MV annulus, LV end diastolic diameter (LVEDD), LV end systolic diameter (LVESD), and shortening fraction (SF). Where requisite views were available, LV end diastolic and end systolic volumes and areas were obtained to calculate LV ejection fraction (EF) by 5/6 Area–Length. For each of the above variables, values were obtained over three consecutive beats and an average for each measurement was recorded and used in function measurements. Where appropriate, Z-scores indexed to BSA were assigned. MV insufficiency, whose severity was obtained from echocardiogram reports, was used as a dichotomous variable in univariate and multivariate analyses, using a break point of moderate or greater MV insufficiency at time of diagnosis as the negative variable.

Long-term follow-up data were collected when available. Medications upon discharge after ALCAPA repair were recorded and included digoxin, diuretics, aspirin, and ACE inhibitors. Status of therapy at last follow-up and total duration of each medication was recorded. Follow-up echocardiogram data were examined by way of echocardiogram reports. Recorded data included function measurements at last follow-up and time to normalization of LV function. Normalization of LV function was defined as a recorded SF greater than 28 % or EF greater than 55 %. Individual SF and EF values as well as BSA at time of normalization were recorded for each normalization event. The presence of areas of dyskinesis or hypokinesis at time of last follow-up or at normalization of function was reported. Time until normalization of LV end diastolic dimension was determined, with normalization defined as LVEDD (cm) indexed for BSA within a Z-score of (−) 2 to (+) 2. We also recorded the degree of mitral regurgitation at time of postoperative discharge and tracked improvement in MR over subsequent follow-up echocardiograms.

Statistical Method

Chi-Square test was used to show significant difference in dichotomous variables between the infant (≤1 year) and non-infant (>1 year) groups. Mann–Whitney U test was used in nonparametric comparisons between these two groups. Logistic regression and Cox Proportional Hazard analyses were used to correlate preoperative variables to postoperative outcomes. Univariable and multivariable models were performed to identify preoperative variables predictive of immediate postoperative morbidities.

Results

A total of 44 patients ranging in age from 1.6 months to 34 years (median 4.5 months) underwent ALCAPA repair during the study period (Table 1; online only). Thirty-two patients were defined as infants (≤1 year of age), making up 73 % of the entire cohort. The remaining 12 patients (27 %) were >1 year of age and were termed the non-infant group. The median weight at repair was 6 kg (range: 3.3–64 kg). For whom data were obtainable, 9/43 (21 %) patients required intubation prior to surgery, all of whom were in the infant group. Preoperative intravenous inotropic support was required in 20/42 (48 %) patients based on clinical judgment at the time of presentation. All twenty of these patients were in the infant group. Twenty-two patients had a preoperative troponin, with elevated levels of >0.08 found in 20/22 (91 %) of patients (mean troponin 0.9). Acidemia (pH <7.35) was demonstrated on arterial blood gas in 13/ 21 (62 %) of patients for whom arterial blood gas was documented on clinical presentation (mean pH 7.32 +/− 0.09, mean bicarbonate 21.4 mmol +/− 3.53). Neither of these preoperative laboratory values were found to be predictive of the primary immediate postoperative outcomes.

Interpretable preoperative electrocardiograms were obtained in 36 patients. All patients showed some evidence of myocardial ischemia or infarction with either T wave inversions (78 %), abnormal Q waves in at least one lead (89 %), ST segment changes (44 %), or all three markers. For the 33 patients in whom infarction patterns were determinable lateral ($n = 9$, 27 %) and anterolateral ($n = 11$, 33 %), infarct patterns were the most common.

Thirty-six of 44 (82 %) total patients had interpretable preoperative echocardiograms available to interpret. Reasons for not having interpretable data from preoperative echocardiograms included studies from very early in the study period that were not on a digital server and whose VHS recordings were not locatable, initial preoperative echocardiogram was done at an outside institution, or initial diagnostic echocardiogram did not contain requisite views from which accurate independent measurements could be obtained. On preoperative echocardiography, the median MV annulus Z-score was 1.8 (range, −1.8 to 6.04) with 41 % of patients having a Z-score >2.0. The median LVEDD Z-score was 7.38 (−1.03 to 17.09) with 90 % of

Table 1 Predictors of duration of postoperative intubation: total cohort and patients <1 year of age

	Univariate analysis			Multivariate analysis		
	Hazard ratio	95 % CI	*p* value	Hazard ratio	95 % CI	*p* value
Total cohort						
Age (months)	1.007	1.003–1.010	<0.001	–	–	–
BSA (m^2)	8.529	3.207–22.686	<0.001	4.388	1.433–13.437	0.01
Weight (kg)	1.052	1.029–1.076	<0.001	–	–	–
Moderate or greater MR	0.653	0.348–1.225	0.184	–	–	–
LVEDd Z-score	0.892	0.825–0.963	0.004	0.9	0.822–0.986	0.023
LVSF	1.093	1.047–1.141	<0.001		–	–
Preoperative intubation	0.531	0.250–1.126	0.099	–	–	–
Preoperative inotropic support	0.49	0.261–0.920	0.026	–	–	–
Patients <1 year of age						
Age (months)	1.007	1.000–1.015	0.051	1.244	1.002–1.546	0.048
Weight (kg)	1.193	0.888–1.603	0.241	–	–	–
Moderate or greater MR	0.872	0.418–1.823	0.717	–	–	–
LVEDd Z-score	0.941	0.860–1.029	0.181	–	–	–
LVSF	1.05	0.976–1.129	0.189	–	–	–
Preoperative intubation	0.692	0.313–1.532	0.364	–	–	–
Preoperative inotropic support	0.854	0.386–1.891	0.697	–	–	–

patients demonstrating a LVEDD Z-score greater than 2, underscoring the severe dilation with which many of these patients present. More specifically, the median preoperative LVEDD Z-score for patients ≤1 year of age was 10 (IQR, 6.7–13.4). In contrast, the 12 non-infant patients diagnosed had a median preoperative LVEDD Z-score of 2.3 (IQR, 1.1–4.5). The median preoperative LV SF was 11 % (IQR, 9–15) for the infant group and 34 % (IQR, 23–36) for patients presenting after one year of age. Only three of the twelve patients diagnosed after 12 months of age had an abnormal SF on initial echocardiogram including an eleven-year-old and twenty-nine-year old patients who had a borderline SF of 23 %, and a three-year-old patient with a SF of 14 %. While these findings support those of Michielon et al. who demonstrated worse SF at time of presentation for infants less than 6 months of age [5], we found no correlation in our infant group between age (0–12 months) and either LVEDD Z-score ($p = 0.108$) or SF ($p = 0.895$). Thus, while the infant group presented with significantly more LV dilation and poorer function than the non-infant group, there was no significant difference in these echocardiographic preoperative variables within ages less than one year.

Underscoring the different manifestations between the infantile and non-infantile forms of ALCAPA, there were statistically significant differences in many preoperative variables between the two groups. Infants had a significantly greater proportion of patients (17/30) with moderate or greater mitral regurgitation than did the non-infantile group (2/11, $p = 0.0285$). No patients older than one year were intubated preoperatively, while 29 % of infants were intubated ($p = 0.036$). Similarly, 66 % of patients less than 1 year of age required preoperative inotropic support, while no patients in the non-infantile group were treated with preoperative inotropic medications ($p < 0.001$).

All patients underwent coronary reimplantation (43 direct reimplantation, 1 Takeuchi procedure). No patients had intervention on the MV. The anomalous left coronary arose from the posterior sinus of the pulmonary valve in the majority of cases (23/44, 52 %). The second most common origin was from the right pulmonary artery (8/44, 18 %), with the third most common origin being the body of the main pulmonary artery (5/44, 11 %). Other origins of the anomalous left coronary included the nonfacing coronary sinus of the pulmonary valve and in between the posterior and nonfacing sinus. In one case, the left anterior descending coronary artery arose from the aorta, while the circumflex originated off the right pulmonary artery. Mean cardiopulmonary bypass time was 118 ± 32 minutes, and mean aortic cross-clamp time was 57 ± 20 minutes.

All patients returned to the ICU intubated and on inotropic support. The overall median duration of intubation was 4 days (0–36 days). Examining the infant group separately, the median duration of postoperative intubation was 6 days (IQR, 4–11 days). The non-infant group was intubated for a median of 1 day. This represents a significantly longer duration of postoperative intubation in the infant group ($p = < 0.001$). On multivariate analysis of the entire cohort, preoperative LVEDD and BSA were found to be independently predictive of duration of postoperative intubation (Table 1). BSA was a stronger surrogate for size in the multivariate model than weight. Analysis was then performed on the infant group as a majority subset. When controlling for preoperative intubation, only age of the infant was found to be independently predictive of duration of postoperative intubation ($p = 0.048$) (Table 1). In infancy, increasing age was a positive risk factor for earlier extubation. That is, with a hazard ratio of >1, an older age at time of repair produced a higher "risk" of being extubated sooner.

The overall median duration of postoperative intravenous (IV) inotropic support was 7 days (0–42 days). Separating out the infant group, the median duration of postoperative IV inotropic support was 12 days (IQR, 5–16 days). The remaining non-infant group required a median duration of postoperative IV inotropy of less than one day. Using a multivariate model, LVEDD Z-score (p 0.009, CI 0.78–0.97), weight (p 0.42, CI 1.00–1.06), and preoperative LV SF (p 0.045, CI 1.00–1.12) all were independent predictors of duration of postoperative IV inotropic support for the entire cohort (Table 2). Controlling for SF, preoperative intubation, and preoperative IV inotropy within the infant group, only LVEDD independently predicted duration of postoperative IV inotropic support (Table 2). Age was similarly used as a continuous variable in both univariate and multivariate analyses of risk factors for duration postoperative inotropic support (Table 2) but was not found to be a significant predictor of duration of inotropic support for infant patients. Preoperative intubation and inotropic support were significant confounders within the infant group, demonstrating effect modification but no independent predictive value on duration of postoperative IV inotropic support (Table 2).

Five patients (12 %) required postoperative mechanical circulatory support and remained on this support for a median duration of 3 days (range, 1–4 days) (Table 2; online only). Mechanical circulatory support included LV assist devices in three patients and extracorporeal membrane oxygenation in two patients. All five of these patients were under six months of age and underwent direct left coronary artery reimplantation. One patient who required mechanical circulatory support (LV assist device) did suffer a hemorrhagic brain infarct on postop day five. In the remaining four patients requiring mechanical support, as in the rest of the entire cohort, there were no other clinically apparent postoperative neurologic events based upon chart

Table 2 Predictors of duration of postoperative IV inotropic support: Total cohort and patients <1 year of age

	Univariate analysis			Multivariate analysis		
	Hazard ratio	95 % CI	*p* value	Hazard ratio	95 % CI	*p* value
Total cohort						
Age (months)	1.007	1.004–1.011	<0.001	–	–	–
BSA(m^2)	10.483	3.36–32.68	<0.001	–	–	–
Weight (kg)	1.051	1.026–1.075	<0.001	1.03	1.001–1.059	0.42
Moderate or greater MR	0.627	0.331–1.188	0.151	–	–	–
LVEDd Z-score	0.835	0.762–0.915	<0.001	0.878	0.797–0.967	0.009
LVSF	1.098	1.054–1.143	<0.001	1.059	1.001–1.121	0.045
Preoperative intubation	0.412	0.193–0.881	0.022	–	–	–
Preoperative inotropic support	0.579	0.311–1.079	0.085	–	–	–
Patients <1 year of age						
Age (months)	1.006	0.998–1.014	0.124	–	–	–
Weight (kg)	1.213	0.875–1.681	0.246	–	–	–
Moderate or greater MR	0.837	0.397–1.763	0.639	–	–	–
LVEDd Z-score	0.887	0.800–0.983	0.22	0.895	0.805–0.996	0.042
LVSF	1.062	0.999–1.129	0.54	–	–	–
Preoperative intubation	0.511	0.230–1.135	0.099	0.511	0.230–1.135	0.099
Preoperative inotropic support	1.077	0.488	2.379	1.077	0.488–2.379	0.854

Table 3 Predictors of time to normalization of LV function

	Univariate analysis			Multivariate analysis		
	Hazard ratio	95 % CI	*p* value	Hazard ratio	95 % CI	*p* value
Age (months)	1.007	1.001–1.002	0.015	–	–	–
BSA(m^2)	12.58	1.684–93.99	0.014	–	–	–
LVEDd Z-score	0.778	0.654–0.925	0.004	0.787	0.651–0.951	0.013
LVEF	1.083	1.017–1.153	0.013	–	–	–
LVSF	1.116	1.03–1.21	0.008	–	–	–
Preop troponin	0.855	0.627–1.165	0.32	–	–	–
Duration of surgical bypass	0.604	0.99–1.017	0.6	–	–	–
Postop mechanical support	1.528	0.433–5.391	0.51	–	–	–
Duration of postop IV inotropy	0.962	0.914–1.013	0.146	–	–	–
Duration of postop intubation	0.956	0.896–1.019	0.169	–	–	–

review through the time of hospital discharge. There were no preoperative factors that were predictive of the need for postoperative mechanical circulatory support on multivariate analysis.

Delayed sternal closure occurred in five patients, excluding those placed on mechanical circulatory support. The median duration of an open chest was 3 days (range, 1–6 days). No preoperative variables independently predicted delayed sternal closure on multivariate regression analysis.

Median length of ICU stay was 7 days (range, 1–55 days) and median length of total hospital stay was 11 days (range, 3–63 days). Considering the infant group as its own entity, media duration of ICU stay was longer at 12.5 days (IQR, 6–18 days). In contrast, patients over one year of age had a median stay in the ICU of 2 days. While duration of mechanical ventilation and length of intravenous inotropic support was statistically influenced by patient size, LVEDD, and SF (for postoperative inotropic duration), none of these variables were

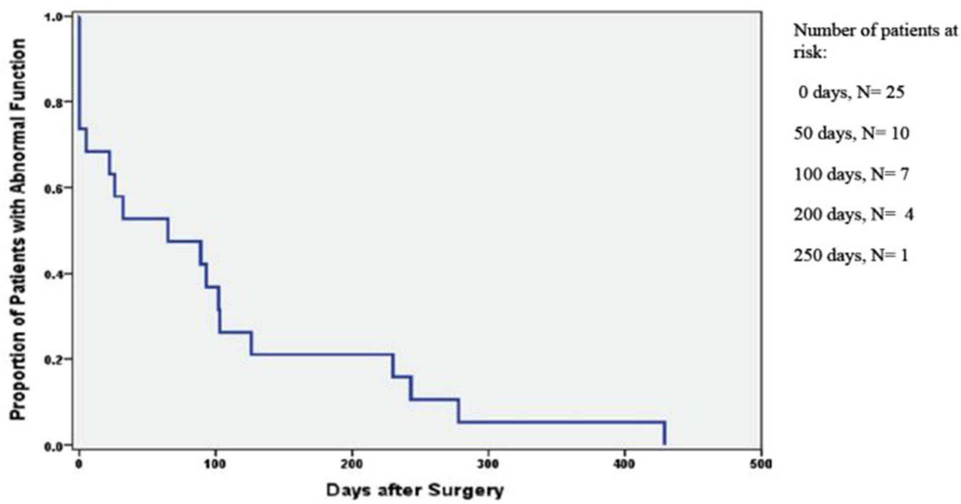

Fig. 1 Time to normalization of left ventricular function following reimplantation of left coronary artery

independently predictive of overall ICU length of stay. There was no in-hospital or late mortality observed in this cohort.

Long-term follow-up data were available for 25 patients with a median follow-up time of 32 months (IQR, 17–114 months) (Table 1; online only). Duration of medication use from time of postoperative discharge was recorded for 20 patients. Anti-congestive heart failure medications were commonly prescribed for patients after coronary reimplantation. The most commonly prescribed medication post-ALCAPA repair was a diuretic, with 80 % (20 of 25) having been discharged on furosemide. Median duration of diuretic use was 109 days (IQR, 79–182 days). Digoxin was utilized in 9/20 (45 %) of patients for whom long-term data were available. Median duration of digoxin use was 185 days (IQR, 123–612 days). ACE inhibitors were used in 11/20 (55 %) of patients for whom follow-up data were available, with a median postoperative duration of 257 days (IQR, 143–355 days). Anticoagulation was prescribed postoperatively in 11/20 (55 %) patients. All but one was prescribed ASA, while one patient was discharged on enoxaparin. Duration of anticoagulation far outpaced that of other anti-congestive medications. Seven patients (35 %) remained on anticoagulation at the time of their last follow-up with median duration of use of 711 days (range, 169–4034). Long-term follow-up echocardiogram data were available for 25 patients. LV function normalized in all 25 (100 %) patients at the time of last follow-up. Median time to normalization of LV function was 91 days (range 5–429 days). This median duration discounts patients who presented at an older age and whose function was normal at time of presentation. At time of normalization of LV function, 13/25 (52 %) patients continued to have areas of dyskinesis or hypokinesis noted on echocardiogram.

At time of last follow-up, 23/25 patients had a normal LVEDD. One patient's LVEDD was not available at the time of last follow-up, and one patient had an LVEDD that had not normalized in the fifteen years since reimplantation. Median time to normalization of LVEDD was 79 days (IQR, 14–234 days). Predictors of time to normalization of LV function on univariate analysis included age, BSA, LVEDD Z-score, LVESD Z-score, and preoperative SF or EF (Table 3). On multivariate analysis, LVEDD Z-score was the only factor independently predictive of time to normalization of LV function. Most patients did not require long-term anti-congestive therapy, as LV function normalized in the vast majority of patients within a year. Kaplan–Meier analysis of normalization of LV function revealed that more than half (60 %) of patients with abnormal function at time of presentation saw their LV function normalize within the first 50 days post-reimplantation (Fig. 1).

Degree of mitral insufficiency (either "mild" or "moderate or greater") did not prove predictive of any of our primary postoperative outcomes or of time until normalization of LV function. At time of discharge, 18/25 (72 %) have some degree of MV regurgitation. Of the 23 patients upon whom mitral regurgitation was commented upon at last follow-up, only 3 patients continued to have mitral regurgitation. The degree of mitral regurgitation was mild in all three patients. Furthermore, of these three patients who still had MR, all had demonstrated improvement or continued mild MR since time of discharge.

Discussion

Previous reviews have been mixed regarding the contribution made by age, BSA, preoperative SF, and LVEDD to mortality. This study demonstrates that immediate postoperative morbidities, such as duration of mechanical ventilation and length of intravenous inotropic support, are influenced by patient size, LVEDD, and preoperative SF. Thus, degree of LV dilation at the time of ALCAPA diagnosis may portend the need for longer ventilatory and inotropic management in the post-reimplantation period. This, however, is not without a degree of bias, as knowledge of severity of preoperative LV dilation may have persuaded the clinicians to wean more slowly off ventilator and inotropic support. Similarly, smaller patients were found to have longer durations of intubation and inotropic support. While a similar bias may play a role in keeping smaller patients on more support for longer periods of postoperative time, size was a predictor independent of observed preoperative function or LV dilation.

Lower preoperative SF independently predicted longer duration of postoperative inotropic support. This predictive value was irrespective of intraoperative variables such as cardiopulmonary bypass and cross-clamp times as well as postoperative LV function. The evaluation of LV systolic function had limitations in this retrospective study. Including a retrospective echocardiographic review in the analysis introduces inherent limitations pertaining to views recorded at the time of the echocardiogram. Function measurements could only be attained with the clips provided. SF, despite its limitations, was the primary assessment of systolic function, as it was the only universal measure able to be applied to studies recorded on VHS, whose fidelity themselves are a limitation when compared to digitally recorded studies. Additionally, it was unclear by medical record review whether the initial preoperative echo was done prior to treatment with preoperative inotropes, upon which 48 % of our cohort was placed. The duration of postoperative inotropy and intubation may have been subject to caregiver bias based on how the preoperative echocardiogram appeared. For instance, having seen a much-dilated LV and exceptionally poor function preoperatively, caregivers may have discriminated against earlier trials off inotropes and extubation in the early postoperative days in the ICU.

Perhaps as important as the predictive value of the above variables is the outcome that preoperative variables were not able to predict, that being requirement of postoperative mechanical circulatory support. Previously, Azakie et al. found patients were more likely to require postoperative ECMO with lower preoperative median EF, more severely dilated left ventricles, and more critical illness at the time of presentation [2]. Our series demonstrated a similar percentage of postoperative patients requiring mechanical support to that documented by Azakie [2] and less that than described by Schwartz [7]. This requirement was not statistically predicted by preoperative function or preoperative LVEDD. Despite the aforementioned limitations of the function measurement, we observed a degree of unpredictability as to who will require postoperative mechanical support following coronary reimplantation. This raises speculation about what interim effects between time of diagnosis and departure from the OR may affect the need for such support. However, no intraoperative variable, including cardiopulmonary bypass time or aortic cross-clamp time was found predictive of need for mechanical circulatory support.

Indeed there was a natural cutoff at approximately one year of age that separated an infant phenotype from a non-infant phenotype, with the clinical presentation of classic heart failure unique to the infant group. The predictive ability of preoperative factors on immediate postoperative morbidity seemed limited to LVEDD and age in this infant group. It should be noted that with respect to duration of IV inotropic support in the infant group, preoperative intubation and inotropic requirement were significant confounders. Both preoperative variables had a reasonable effect on LVEDD as an independent predictor of duration of postoperative IV inotropic support.

Similarly for the entire cohort, the preoperative LV function and LVEDD Z-score were co-linear, and while the LVEDD Z-score was found predictive of time to normalization of LV function, the preoperative function likely has reasonable effect. Interestingly, postoperative mechanical support did not predict longer time to normalization of LV function. This is encouraging for that subset of infants who require mechanical circulatory support in the setting of cardiopulmonary bypass- mediated exacerbation of already depressed LV function. The degree of mitral regurgitation improved from time of discharge to last follow-up, with most patients being left with no or trivial MR, coinciding with the findings of Lange, et al [4]. Schwartz et al. [7] found increased severity of mitral regurgitation predictive of mortality. In our study, the degree of MR at diagnosis did not predict postoperative morbidity and the degree of MR at discharge did not influence normalization of LV function. Rather, prognostic value for immediate ICU morbidity and long-term recovery of function arises from the degree of LV dilation at time of diagnosis. Based on these results, we maintain that coronary reimplantation without intervention on the MV and careful surveillance of valve function over time is a reasonable approach to these patients.

Conclusion

In one of the largest series described to date, ALCAPA repair without MV intervention has excellent outcomes in the current era, with no mortality observed in our cohort. Our study examined preoperative variables that predict postoperative morbidities in the ICU. Immediate postoperative morbidities, such as duration of mechanical ventilation and length of intravenous inotropic support are influenced by patient size, LVEDD, and preoperative systolic function. Specifically LVEDD, weight, and LV SF were independent predictors of duration of postoperative inotropic support. LVEDD and BSA were found to be independently predictive of duration of postoperative intubation. Equally as important, we found no preoperative variables predictive of delayed sternal closure, need for mechanical circulatory support, or overall length of ICU stay. The infantile presentation of ALCAPA is a clinically and pathologically distinct phenotype whose postoperative course is influenced by the degree of LV dilation. Normalization of LV function occurs in all patients, typically within the first postoperative year. When controlling for age, the LVEDD was independently predictive of time to normalization of LV function. Most patients with ALCAPA will have some degree of mitral regurgitation. However, even without intervention upon the MV at time of ALCAPA repair, the regurgitation tends to improve with the majority of patients for whom long-term data were available having full resolution. While anti-congestive medication is common after ALCAPA repair, most patients do not require long-term therapy.

Conflict of interest Justin Weigand declares they have no conflict of interest. Clement Douglass Marshall declares they have no conflict of interest. Emile A. Bacha declares they have no conflict of interest. Jonathan M. Chen declares they have no conflict of interest. Marc E. Richmond declares they have no conflict of interest.

Disclosures Justin Weigand, MD has no honorarium, Grant, or other form of payment was given to produce the manuscript.

References

1. Allen HD, Adams FH, Moss AJ (2001) Moss and Adams' heart disease in infants, children, and adolescents : including the fetus and young adult, 6th edn. Lippincott Williams and Wilkins, Philadelphia
2. Azakie A, Russell JL, McCrindle BW, Van Arsdell GS, Benson LN, Coles JG et al (2003) Anatomic repair of anomalous left coronary artery from the pulmonary artery by aortic reimplantation: early survival, patterns of ventricular recovery and late outcome. Ann Thora Surg 75(5):1535–1541
3. Cowles RA, Berdon WE (2007) Bland-White-Garland syndrome of anomalous left coronary artery arising from the pulmonary artery (ALCAPA): a historical review. Pediatr Radiol 37(9):890–895
4. Lange R, Vogt M, Horer J, Cleuziou J, Menzel A, Holper K et al (2007) Long-term results of repair of anomalous origin of the left coronary artery from the pulmonary artery. Ann Thora Surg 83(4):1463–1471
5. Michielon G, Di Carlo D, Brancaccio G, Guccione P, Mazzera E, Toscano A et al (2003) Anomalous coronary artery origin from the pulmonary artery: correlation between surgical timing and left ventricular function recovery. Ann Thorac Surg 76(2):581–588 discussion 8
6. Sauer U, Stern H, Meisner H, Buhlmeyer K, Sebening F (1992) Risk factors for perioperative mortality in children with anomalous origin of the left coronary artery from the pulmonary artery. J Thorac Cardiovasc Surg 104(3):696–705
7. Schwartz ML, Jonas RA, Colan SD (1997) Anomalous origin of left coronary artery from pulmonary artery: recovery of left ventricular function after dual coronary repair. J Am Coll Cardiol 30(2):547–553