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ORIGINAL RESEARCH

Long-Term Fate of the Truncal Valve

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BACKGROUND: Long-term survival in patients with truncus arteriosus is favorable, but there remains significant morbidity associated with ongoing reinterventions. We aimed to study the long-term outcomes of the truncal valve and identify risk factors associated with truncal valve intervention.

METHODS AND RESULTS: We retrospectively reviewed patients who underwent initial truncus arteriosus repair at our institution from 1985 to 2016. Analysis was performed on the 148 patients who were discharged from the hospital and survived ≥30 days postoperatively using multivariable competing risks Cox regression modeling. Median follow-up time was 12.6 years (interquartile range, 5.0–22.1 years) after discharge from full repair. Thirty patients (20%) underwent at least one intervention on the truncal valve during follow-up. Survival at 1, 10, and 20 years was 93.1%, 87.0%, and 80.9%, respectively. The cumulative incidence of any truncal valve intervention by 20 years was 25.6%. Independent risk factors for truncal valve intervention included moderate or greater truncal valve regurgitation (hazard ratio [HR], 4.77; $P<0.001$) or stenosis (HR, 4.12; $P<0.001$) before full truncus arteriosus repair and moderate or greater truncal valve regurgitation at discharge after full repair (HR, 8.60; $P<0.001$). During follow-up, 33 of 134 patients (25%) progressed to moderate or greater truncal valve regurgitation. A larger truncal valve root *z*-score before truncus arteriosus full repair and during follow-up was associated with worsening truncal valve regurgitation.

CONCLUSIONS: Long-term rates of truncal valve intervention are significant. At least moderate initial truncal valve stenosis and initial or residual regurgitation are independent risk factors associated with truncal valve intervention. Larger truncal valve root *z*-score is associated with significant truncal valve regurgitation and may identify a subset of patients at risk for truncal valve dysfunction over time.

Key Words: congenital heart disease ■ truncal valve ■ truncus arteriosus

Truncus arteriosus (TA) is rare, accounting for 2% to 4% of all congenital heart disease. Since the mid-1980s, the surgical strategy for TA has focused on complete neonatal repair. Subsequent catheter and surgical reinterventions, most commonly for right ventricular to pulmonary artery conduit dysfunction, are generally accepted as part of the clinical course.[1–4] Neonatal truncal valve dysfunction is frequent in patients with TA, with regurgitation more commonly present than stenosis.[2,5,6] However, the progression of truncal valve regurgitation and the need for valve repair or replacement remain poorly characterized. Prior literature has suggested valve morphological features, concomitant truncal valve surgery at initial repair, and initial degree of truncal valve regurgitation as possible risk factors for the need for truncal valve intervention on follow-up.[2,7,8] Given the inconsistencies between studies and to help guide patient long-term monitoring and counseling, the purpose of this study is to identify risk factors of truncal valve intervention following full repair.

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CLINICAL PERSPECTIVE

What Is New?

- By 20 years, a quarter of patients with truncus arteriosus underwent truncal valve intervention (repair or replacement).
- Moderate or greater initial truncal valve dysfunction and single coronary ostium were associated with subsequent need for truncal valve intervention.
- Patients with truncus arteriosus born with less than moderate truncal valve regurgitation remain at risk for progression of regurgitation and undergoing truncal valve intervention; progression of truncal valve regurgitation is associated with increased truncal root size.

What Are the Clinical Implications?

- Truncal root *z*-scores may be useful to further risk stratify and monitor patients with truncus arteriosus.

Nonstandard Abbreviations and Acronyms

BCH	Boston Children's Hospital
TA	truncus arteriosus

METHODS

The data that support the findings of this study are available from the corresponding author on reasonable request. The study was approved by the Boston Children's Hospital (BCH) Institutional Review Board, and individual patient consent was waived.

Study Population

We retrospectively reviewed all patients who underwent surgery for TA from 1985 to 2016 at BCH. Patients were only included if their initial surgical procedure occurred at BCH. Patients were excluded if they did not reside in one of the common BCH catchment areas at the time of surgery (Massachusetts, Connecticut, Rhode Island, Maine, New Hampshire, Vermont, New York, New Jersey, Pennsylvania, and Delaware) to ensure adequate follow-up of patients.

Data Collection and Definitions

Baseline and clinical characteristics were extracted from the clinical records. The degree of truncal valve regurgitation and stenosis was determined by echocardiography based on previously published guidelines and extracted from reports.[9] Collected data included *z*-score measurements, which calculate for a given measurement how many SDs above or below it is from a size-specific normal population mean.[10] TA type was categorized using the Van Praagh classification.[11] Initial TA repair was defined as surgery that consisted of ventricular septal defect closure, detachment of the pulmonary arteries from the common trunk, and establishment of continuity between the right ventricle and pulmonary arteries. All reinterventions, defined broadly as any interventional catheterization or surgery that followed initial repair, were documented, with truncal valve intervention as the primary outcome for this study.

Vital status for patients without clinical follow-up documentation at BCH since January 1, 2017, was obtained from the National Death Index of the National Center for Health Statistics. Early mortality was defined as death occurring ≤30 days postoperatively or before hospital discharge. Long-term outcomes were assessed in patients who were discharged from the hospital following the initial repair and survived >30 days postoperatively. The primary outcomes of this study were truncal valve intervention and mortality after discharge from initial full repair. Secondary outcomes of the study were time to any surgical reintervention and the binary measures of at least moderate truncal valve regurgitation.

Statistical Analysis

Data are presented with descriptive statistics using means and SD, and medians with interquartile range for continuous variables. Categorical data are described as frequencies with percentages. A Fisher exact test, Student *t* test, or Wilcoxon rank-sum test was used to compare baseline characteristics by patient group.

Time-to-event distributions were estimated using the Kaplan-Meier method, where time 0 was the date of hospital discharge from initial TA repair. Patients were censored at the time of the most recent follow-up if they did not have an event.

Because death is a form of informative censoring, death was treated as a competing risk to obtain unbiased estimates of the cumulative incidence of truncal valve intervention. Estimates of cumulative incidence rates over time for death and for truncal valve intervention are presented. A proportional subdistribution hazards regression model, described by Fine and Gray,[12] was constructed to assess association between predictors and time to truncal valve intervention. Stepwise model selection was performed by including all candidates with a univariate $P<0.15$ (with the exception of clinical event indicators occurring after time 0) to create a multivariable competing risks Cox regression model of factors independently associated with time to truncal valve intervention. $P<0.10$ was required for entry into the model, and $P<0.05$ was required for staying in the model. Generalized

linear mixed effects regression with logit link was used to model serial assessments of the secondary outcome for the study, moderate or greater truncal valve regurgitation. $P<0.05$ was considered statistically significant. Analyses were performed with SAS version 9.4 (SAS Institute, Inc, Cary, NC).

RESULTS

From 1985 to 2016, a total of 244 patients underwent initial TA repair at BCH. Of these patients, 170 met the criteria for analysis (Figure S1). The median age at the time of full TA repair was 10.5 days (range, 1–257 days), with overall 40.6% (n=69) undergoing surgery at <7 days of age. The median age at surgery decreased from 27.5 days (n=70) in 1985 to 1994 to 6 days (n=100) in 1995 to 2016 ($P<0.001$).

The overall early mortality rate was 13% (n=22/170). Five deaths occurred on the day of the TA operation, 13 deaths occurred within 30 days postoperatively, and 4 deaths occurred during prolonged hospitalizations after 30 days. Early mortality rate decreased from 20% (n=14) in 1985 to 1994 to 8% (n=8) in 1995 to 2016 ($P=0.03$).

Overall, 9% (n=15/170) of patients underwent concomitant truncal valve surgery at time of initial repair. Two thirds (n=10/15) of these patients had a quadricuspid valve. Aside from 2 of the patients (1 of whom was an extremely premature infant and underwent repair near gestational age after several months of life), the concomitant truncal valve repairs were all performed in neonates. Eleven patients had greater than mild preoperative truncal valve regurgitation, and the remaining 4 patients had moderate or severe truncal valve stenosis. Three patients also had concomitant left coronary artery intervention: unroofing, translocation, and removal of fibrous tissue at the ostium.

One patient with concomitant truncal valve surgery underwent neonatal replacement and died on postoperative day 2. There were 3 additional early deaths. Two patients were unable to come off bypass in the operating room, one had type 4 TA and the other had predominant truncal valve stenosis and signs of necrotizing enterocolitis pre-operatively repair. The third patient returned to the operating room on postoperative day 1 for low cardiac output in setting of moderate to severe persistent truncal regurgitation requiring extracorporeal membrane oxygenation support, and ultimately care was redirected on postoperative day 4.

Long-term outcomes were assessed in the 148 patients who survived >30 days postoperatively and to hospital discharge. Baseline characteristics are listed in Table 1. Of these patients, the median time of follow-up was 12.6 years (interquartile range, 5.0-22.1 years), and 19% (n=28/148) died or underwent heart transplantation (n=1). Nine deaths (33%) occurred within 1 year of initial repair. Of the 14 known causes of death, 4 were out-of-hospital arrests (2 with known coronary anomalies), 2 were related to sepsis presentations (without known DiGeorge syndrome), and 4 were related to cardiac procedure complications (Table S1). Among the long-term survivors, 68 patients (46%) had TA type 1, and 24 patients (16%) had TA type 4 (aortic arch coarctation or interruption). Forty-five patients (32%) had a quadricuspid valve. Forty-two patients (28%) had coronary artery anomalies, which were defined as stenosis or atresia, intramural course, and abnormal origins, of which 8 patients (5%) had a single coronary ostium. Before full TA repair, 71 patients (49.3%) had none or trivial regurgitation, 54 patients (37.5%) had mild regurgitation, 18 patients (12.5%) had moderate regurgitation, and 1 patient (0.7%) had severe regurgitation. A total of 10 patients (7%) had greater than mild truncal valve stenosis. Of the patients with moderate or greater initial regurgitation, 15 (79%) had a quadricuspid valve.

All Reinterventions

Overall, 123 patients (83%) underwent at least one surgical or catheter-based intervention during follow-up (Table S2). Freedom from any surgical reintervention at 1, 5, 10, and 20 years was 90.0%, 50.0%, 21.0%, and 6.0%.

Truncal Valve Repair and Replacement

Among the long-term cohort, 11 patients had concomitant truncal valve surgery at initial TA repair and 137 patients had no concomitant truncal valve surgery. During follow-up, 30 patients (20%) had at least one surgical intervention on the truncal valve, 24 of whom were from the group without concomitant truncal valve surgery (first intervention on the truncal valve occurred subsequently during follow-up) (Figure 1). Among those with only subsequent truncal intervention, 16 underwent repair first and 8 underwent replacement without prior repair. Of note, those who underwent replacement were older (median age, 18.3 [range, 1.1–23.0] years versus 8.3 [range, 2.3–16.8] years; $P=0.04$) and with larger aortic root size at time of intervention than truncal valve repair (median aortic root size, 4.37 [range, 2.82–4.92] cm versus 3.39 [range, 2.35–4.76] cm; $P=0.04$). Four patients had >1 valve repair, and 3 patients went on to have a second valve replacement during follow-up. Of the 11 long-term survivors with concomitant truncal valve surgery at initial repair, 6 went on to have truncal valve reintervention during follow-up. Overall

Table 1. Patient and Surgical Characteristics by Outcome With Univariate Model Results for Time to Truncal Valve Intervention

Variable	Overall (n=148)	Truncal Valve Intervention (n=30)	Death (n=24)	No Death or Truncal Valve Intervention (n=94)	HR (95% CI)
Age at surgery, d	10.0 (5.0–33.5)	6.5 (4.0–20.0)	16.5 (5.5–61.5)	10.5 (5.0–35.0)	0.99 (0.98–1.01)
Age at surgery, d					
≤7	61 (41.2)	16 (53.3)	7 (29.2)	38 (40.4)	3.14 (0.77–12.71
8–30	47 (31.8)	8 (26.7)	7 (29.2)	32 (34.0)	1.98 (0.44–8.80)
31–90	19 (12.8)	4 (13.3)	5 (20.8)	10 (10.6)	2.55 (0.49–13.39)
>90	21 (14.2)	2 (6.7)	5 (20.8)	14 (14.9)	Reference
Era of surgery					
1985–1994	56 (37.8)	11 (36.7)	14 (58.3)	31 (33.0)	1.48 (0.54–4.05)
1995–2004	46 (31.1)	13 (43.3)	5 (20.8)	28 (29.8)	2.27 (0.84–6.09)
2005–Present	46 (31.1)	6 (20.0)	5 (20.8)	35 (37.2)	Reference
Male sex	79 (53.4)	13 (43.3)	17 (70.8)	49 (52.1)	0.64 (0.31–1.31)
Birth weight, kg	3.1 (2.7–3.4)	3.3 (3.0–3.6)	3.4 (2.5–3.7)	3.0 (2.6–3.3)	1.91 (1.09–3.37)
Type of truncus					
A1	68 (45.9)	14 (46.7)	8 (33.3)	46 (48.9)	0.67 (0.28–1.63)
A2	44 (29.7)	8 (26.7)	8 (33.3)	28 (29.8)	0.60 (0.22–1.66)
A3	12 (8.1)	1 (3.3)	4 (16.7)	7 (7.4)	0.26 (0.03–2.10)
A4	24 (16.2)	7 (23.3)	4 (16.7)	13 (13.8)	Reference
Truncal valve morphological features					
Quadricuspid	45 (32.1)	23 (76.7)	5 (23.8)	17 (19.1)	9.69 (4.24–22.13)
Bicuspid/tricuspid	95 (67.9)	7 (23.3)	16 (76.2)	72 (80.9)	Reference
Associated anomalies					
Right aortic arch	42 (28.4)	10 (33.3)	9 (37.5)	23 (24.5)	1.32 (0.62–2.82)
PDA	34 (23.0)	9 (30.0)	5 (20.8)	20 (21.3)	1.50 (0.69–3.25)
PFO/ASD	135 (91.2)	29 (96.7)	21 (87.5)	85 (90.4)	2.96 (0.39–22.33)
Anomalous vein	11 (7.4)	2 (6.7)	3 (12.5)	6 (6.4)	0.89 (0.21–3.75)
Extracardiac anomaly	24 (16.2)	6 (20.0)	5 (20.8)	13 (13.8)	1.30 (0.54–3.11)
DiGeorge syndrome	28 (18.9)	4 (13.3)	4 (16.7)	20 (21.3)	0.64 (0.22–1.83)
Other genetic syndrome	14 (9.5)	4 (13.3)	2 (8.3)	8 (8.5)	1.49 (0.54–4.08)
Coronary anomalies	42 (28.4)	9 (30.0)	10 (41.7)	23 (24.5)	1.13 (0.51–2.48)
Single coronary ostium	8 (5.4)	3 (10.0)	2 (8.3)	3 (3.2)	2.43 (0.68–8.76)
Initial truncal valve regurgitation					
None/trivial	71 (49.3)	4 (13.3)	14 (63.6)	53 (57.6)	
Mild	54 (37.5)	13 (43.3)	6 (27.2)	35 (38.0)	
Moderate	18 (12.5)	13 (43.3)	1 (4.5)	2 (2.2)	
Severe	1 (0.7)	0 (0)	1 (4.5)	2 (2.2)	
Initial truncal valve regurgitation moderate or greater	19 (13.2)	13 (43.3)	2 (9.1)	4 (4.3)	7.85 (3.84–16.06)
Initial truncal valve stenosis moderate or greater	10 (7.0)	7 (24.1)	3 (13.0)	0 (0)	5.98 (3.84–16.06)
Initial truncal valve *z*-score	3.7 (3.0–4.4)	3.7 (3.5–4.3)	3.6 (3.5–4.4)	3.7 (2.8–4.5)	1.05 (0.76–1.44)
Concomitant truncal valve repair at surgery	11 (7.4)	6 (20.0)	2 (8.3)	3 (3.2)	4.56 (1.76–11.79)
Truncal valve regurgitation at discharge moderate or greater	14 (10.9)	10 (35.7)	1 (4.8)	3 (3.8)	7.56 (3.46–16.54)
Truncal valve *z*-score at discharge	4.3±1.7	5.0±3.3	3.8±2.3	4.3±1.3	1.28 (0.48–3.38)

Data are given as median (interquartile range), number (percentage), or mean±SD. ASD indicates atrial septal defect; HR, hazard ratio; PDA, patent ductus arteriosus; and PFO, patent foramen ovale.

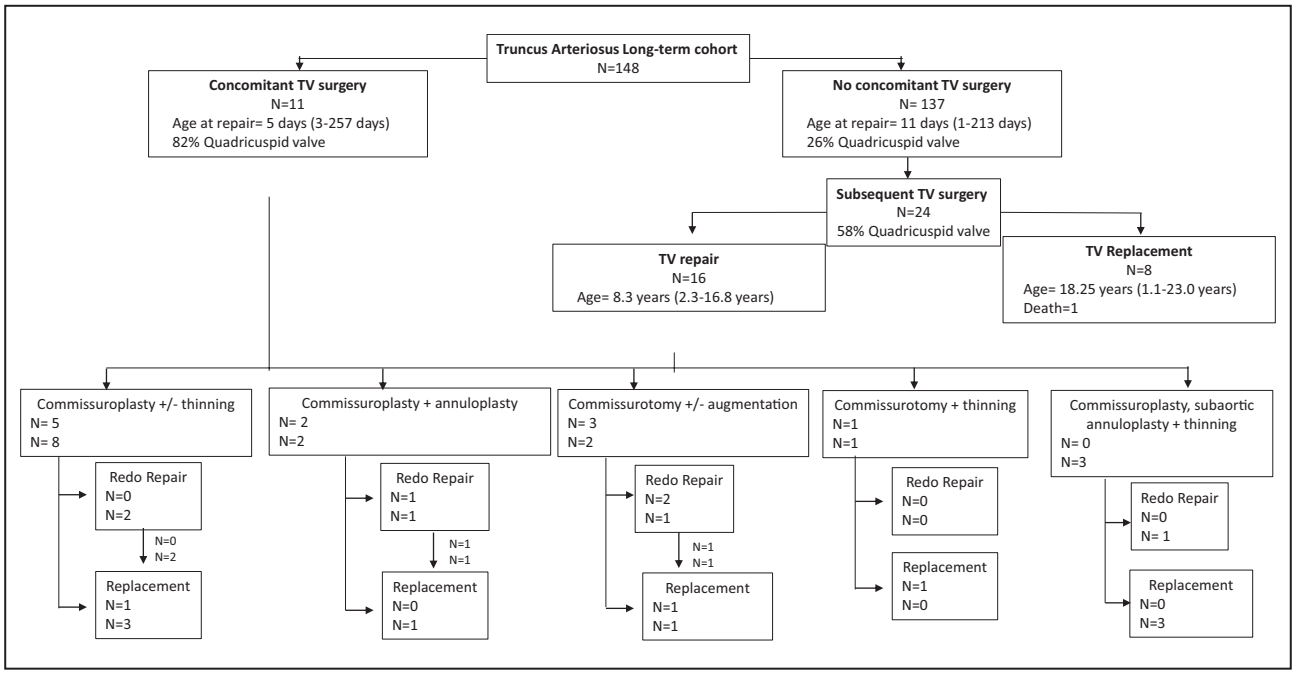

Figure 1. Flowchart of truncal valve (TV) surgeries.
Median value (number of patients with data, value range) displayed. First row represents patients with concomitant TV surgeries. Second row represents subsequent TV surgeries.

repair strategies are outlined in Figure 1. In both the concomitant truncal valve surgery group and subsequent truncal valve surgery group, commissuroplasty was most commonly performed and frequently accompanied by leaflet thinning. All patients, except 1, had at least moderate truncal valve regurgitation before intervention. Three of the patients with intervention on the truncal valve died, and 1 underwent heart transplantation during long-term follow-up.

Of the 50 total truncal valve intervention events during follow-up (repair and replacement combined), all had preoperative echocardiographic data available, and preoperative cardiac magnetic resonance imaging was available for 24 cases. Both modalities demonstrated preserved left ventricular systolic function and significant left ventricular dilation in most patients (Tables S3 and S4).

Figure 2 shows the cumulative incidences of any truncal valve intervention and death. Survival by 1, 5, 10, and 20 years after initial hospital discharge was 93.1%, 88.7%, 87.0%, and 80.9%, respectively. The cumulative incidence of any truncal valve intervention by 1, 5, 10, and 20 years was 0.7%, 5.1%, 15.6%, and 25.6%, respectively. When stratified into truncal valve repair and replacement as first truncal valve intervention during follow-up, by 10 years after initial hospital discharge, the cumulative incidence of truncal valve repair was 12.3% and replacement was 3.3% (Figure 3).

Univariate modeling results to identify risk factors for truncal valve intervention are presented in Table 1. In multivariable analysis (Table 2), 4 independent risk factors were identified: moderate or greater preoperative initial truncal valve regurgitation (hazard ratio [HR], 4.7; 95% CI, 2.26–10.07) or stenosis (HR, 4.12; 95% CI, 2.11–8.04), and moderate or greater truncal valve regurgitation at initial hospital discharge after full repair (HR, 8.6; 95% CI, 3.95–18.69) (Figure 4). The fourth independent risk factor was the anomaly of a single coronary ostium (HR, 6.94; 95% CI, 1.5–21.19). No patient

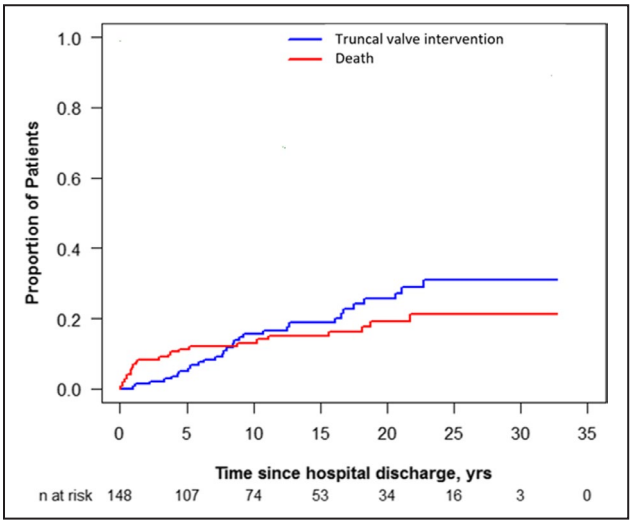

Figure 2. Cumulative incidence of competing risks of death and any truncal valve intervention.
At any given time point, the incidence of all states totals to 100%.

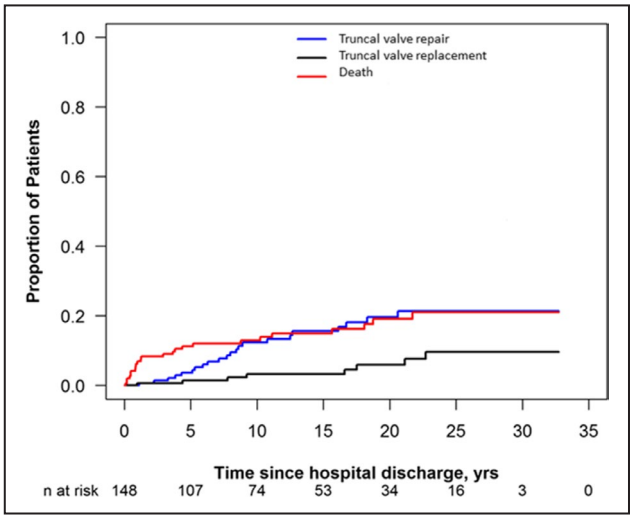

Figure 3. Cumulative incidence of death, truncal valve repair, and truncal valve replacement.
At any given time point, the incidence of all states totals to 100%.

had greater than mild truncal valve stenosis at initial hospital discharge.

Quadricuspid truncal valve (n=45/140) and concomitant truncal valve surgery at initial repair (n=11/148) were univariate risk factors for truncal valve intervention, but did not remain independent risk factors in multivariable analysis. Of those with quadricuspid valve, 33% (15/45) had moderate or greater initial truncal regurgitation and about half (23/45) underwent truncal valve intervention during follow-up. As mentioned above, 6 patients who had concomitant truncal valve surgery went on to have subsequent intervention on the truncal valve.

Among the patients with coronary anomalies in the long-term cohort, 9 (21%) had moderate or greater initial truncal valve regurgitation, as mentioned above, 3 had concomitant coronary interventions at time of initial

Table 2. Multivariable Model for Time to Truncal Valve Intervention

Variable	Hazard Ratio	95% CI	*P* Value
Single coronary ostium			
Yes	6.94	1.50–21.19	0.013
No	Reference		
Preoperative truncal valve regurgitation			
Moderate or greater	4.77	2.26–10.07	<0.001
Less than moderate	Reference		
Preoperative truncal valve stenosis			
Moderate or greater	4.12	2.11–8.04	<0.001
Less than moderate	Reference		
Predischarge truncal valve regurgitation			
Moderate or greater	8.60	3.95–18.69	<0.001
Less than moderate	Reference		

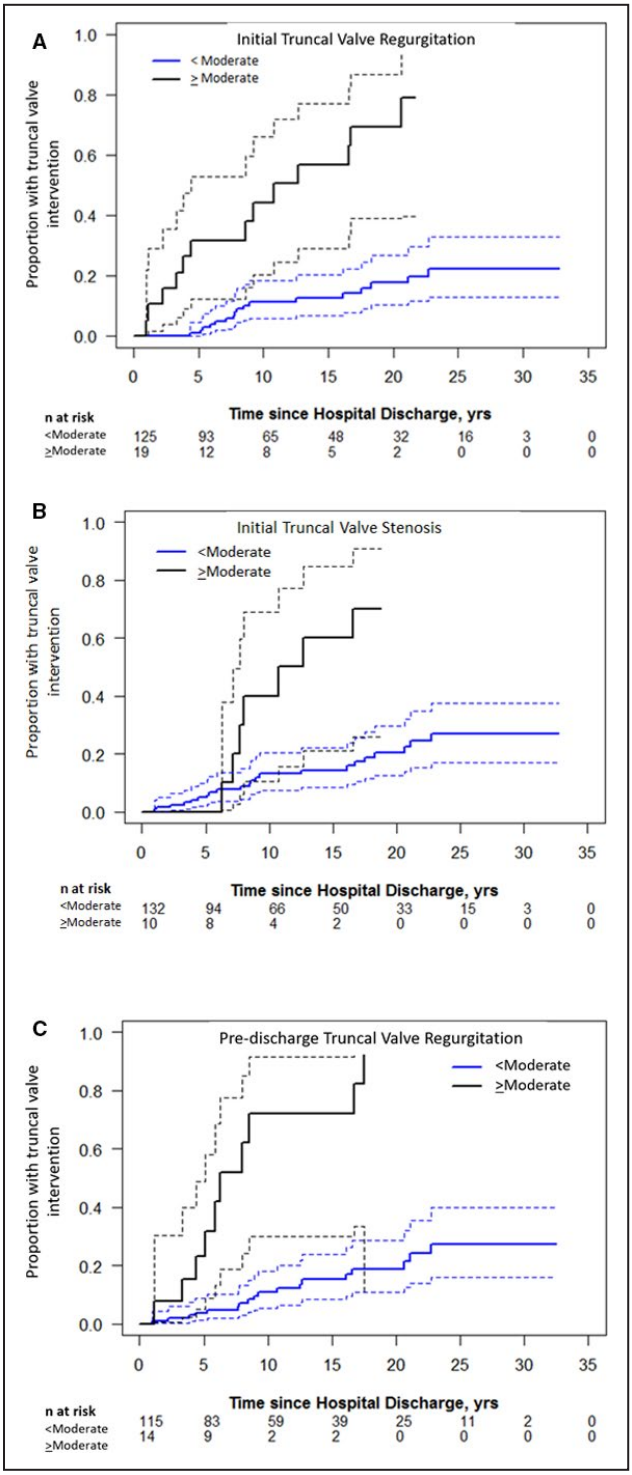

Figure 4. Time to truncal valve intervention by risk factor.
A, Initial preoperative truncal valve regurgitation. **B**, Initial preoperative truncal valve stenosis. **C**, Predischarge truncal valve regurgitation.

repair, and 9 went on to have truncal valve intervention during follow-up. There were overall 6 coronary artery interventions during follow-up, all of which took place at time of truncal valve intervention. Five consisted of left coronary artery unroofing for intramural courses,

and one consisted of reimplantation. Of the 8 patients specifically with single coronary ostium, only 1 had initial moderate or greater truncal regurgitation and underwent aortic root and valve replacement at 28 years of age along with left coronary artery unroofing. Two additional patients progressed to moderate or greater truncal regurgitation and had subsequent truncal valve repair without coronary artery intervention.

Among patients without initial concomitant truncal valve surgery and discharged with less than moderate truncal valve regurgitation (n=131 of 148), 117 hadechocardiographic data for review. With a median of 12.7 years of follow-up, 33 patients (28%) progressed to at least moderate truncal valve regurgitation during follow-up. Freedom from development of moderate or greater truncal valve regurgitation at 1, 5, 10, and 20 years was 93.9%, 80.9%, 75.2%, and 60.7%, respectively (Figure 5). Of those who developed at least moderate truncal valve regurgitation, 14 underwent truncal valve repair during the study period, with a median time to intervention of 10.0 years (range, 5.3–18.3 years) after discharge. Among those who did not develop significant regurgitation, 1 patient underwent truncal valve intervention during follow-up at time of conduit revision with leaflet thinning and commissuroplasty.

Development of moderate or greater truncal valve regurgitation was associated in univariate analysis with larger truncal root *z*-scores both at baseline before TA repair (odds ratio [OR], 2.1; 95% CI, 1.06–4.29; *P*=0.03) and during follow-up (OR, 1.67; 95% CI, 1.24–2.24; *P*=0.001). Specifically, a truncal root *z*-score of ≥5 had a significantly higher odds of developing moderate or greater truncal valve regurgitation (OR, 6.91; 95% CI, 2.16–22.09; *P*=0.002). Freedom from a truncal root *z*-score ≥5 at 1, 5, 10, and 20 years decreased to 95%, 77%, 67%, and 37%, respectively (Figure 6). Patients who underwent truncal valve intervention during follow-up were more likely to have larger truncal root *z*-scores compared with those who were living without truncal valve intervention at the latest follow-up (median *z*-score, 5.9 [interquartile range, 4.3–7.6] versus 4.1 [interquartile range, 3.2–5.6]; *P*=0.032). During follow-up, 10 patients (7%) underwent truncal root reduction (2 at time of surgery for conduit exchange without truncal valve intervention, 4 at time of truncal valve replacement, and 4 at time of truncal valve repair). No patients experienced aortic dissection.

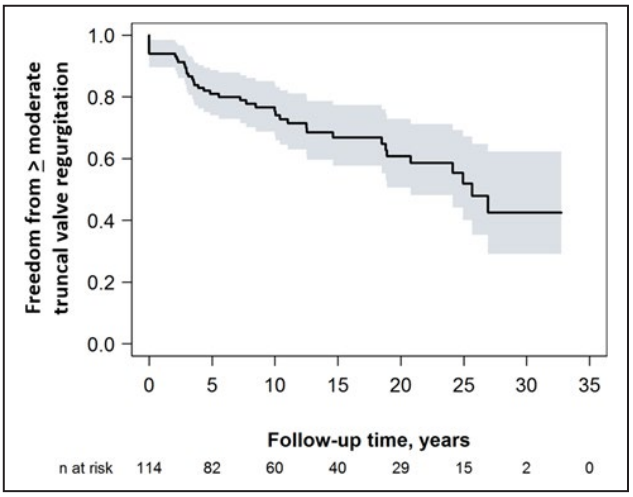

Figure 5. Freedom from moderate or greater truncal valve regurgitation.
Shaded area denotes pointwise 95% confidence bands.

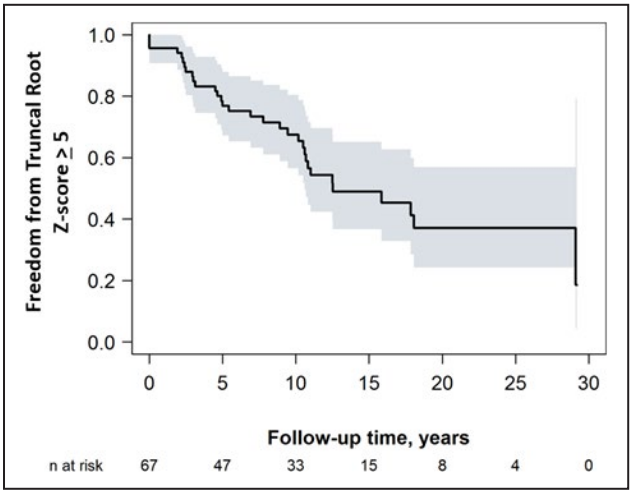

Figure 6. Freedom from truncal root *z*-score ≥5.
Shaded area denotes pointwise 95% confidence bands.

DISCUSSION

This study demonstrates that although mortality rates have continued to improve over time for patients with TA, the need for truncal valve repair and replacement remains a frequent component of their long-term care, with almost a quarter requiring intervention by 20 years. Our single institution rates of truncal valve intervention are similar to prior reports that showed freedom from truncal valve intervention, ranging from 63% to 75% by 18 years.[7,13]

For counseling and monitoring patients on long-term outcomes, it is generally accepted that the right ventricular to pulmonary artery conduit will need replacement, but data predictive of the need for truncal valve intervention are less well defined. Initial truncal regurgitation is not uncommon,[2,5,6] and we show in this study it is associated with the need for truncal valve intervention over time. Similar to prior work by Henaine et al, we found that initial moderate or greater truncal valve dysfunction was associated with the need for subsequent truncal valve intervention.[7]

Other work by Naimo et al[14] has shown quadricuspid truncal valve morphological features to be

associated with need for truncal valve intervention. Although our study found a similar frequency of quadricuspid valve morphological features among those who underwent truncal intervention (present in ≈77% of patients with truncal valve intervention), when controlling for regurgitation, this did not remain independently associated with intervention. This may reflect the individual variability of leaflet size, shape, and composition, even among those with the same number of leaflets; further work is clearly needed to better characterize valve leaflet structural factors that may drive long-term outcomes.

Interestingly, our study differs from Naimo et al[14] in regard to outcomes for those patients who could be considered lower risk with less than moderate truncal regurgitation initially. Naimo et al[14] reported that the overwhelming majority of patients with mild or less truncal valve regurgitation (who did not undergo concomitant intervention) did not have progression of regurgitation during follow-up and that freedom from truncal valve intervention in this group was 84% at 20 years. However, among this lower-risk population in our cohort, 28% still went on to develop at least moderate regurgitation over time, with half of these patients undergoing truncal valve intervention during follow-up. One notable baseline difference between these 2 studies is the age at time of initial TA surgery. In the study by Naimo et al, only approximately one third of the patients were neonates at time of TA repair during the study period compared with our cohort, in which 73% were neonatal surgeries. This may be one of the factors driving differences in reported outcomes between the 2 studies as we found age at time of initial TA repair to not be significantly different between groups.

Our results show an association between this progression of truncal valve regurgitation over time and the baseline truncal root *z* scores at initial repair and during follow-up. Specifically, a truncal root *z*-score of >5 had a higher odds of developing moderate or greater regurgitation over time. This suggests that perhaps truncal root *z*-scores could be used to help risk stratify and monitor patients who may appear, on the basis of initial degree of truncal regurgitation, to be lower risk for truncal valve intervention.

This study also suggests that a single coronary ostium is associated with increased likelihood of truncal valve intervention during follow-up; nearly half of the patients in our cohort with single coronary ostium went on to have subsequent truncal valve interventions. Coronary anomalies have previously been reported to be associated with concomitant truncal valve repair at initial TA[8] and mortality.[2,3,15] Recent work by Naimo et al[15] showed, in a multicenter review of TA patients in Australia, that single ostium was the most common coronary anomaly variant observed. However, in our cohort, a single coronary ostium was not independently associated with valve morphological features (specifically, quadricuspid morphological features); this may be a marker for more subtle leaflet structural abnormalities, and this deserves further careful investigation.

Finally, the influences of concomitant truncal valve repair at time of initial TA surgery and surgical technical approaches at repair on outcomes remain unclear. The ability to repair truncal valve regurgitation over the years has improved in neonates, children, and young adults.[4,16–19] Recent work by Konstantinov et al[20] described their successful surgical approach for a neonate with severe truncal regurgitation, left ostial stenosis, and intramural course, demonstrating the advances that have occurred in the field. However, although concomitant truncal valve repair is feasible and improving, the durability of these repairs may be limited.[4,14,16–19] Naimo et al[14] reported that among the 20 patients who underwent concomitant truncal valve surgery, 65% underwent truncal valve reintervention at a median time of 2.4 years. Similarly, Kaza et al[17] found that, among those with concomitant truncal valve repair, freedom from reintervention was 50% by 7 years postoperatively. Our results suggest similar limitations to concomitant truncal valve repair, with over half (n=6/11) of our patients undergoing subsequent valve intervention. We were not powered to examine the influence of different repair strategies. However, a common theme among prior works, and now our own, remains the heterogeneity of truncal valves and need for an individualized approach to each repair.

Limitations

This study is limited by its retrospective design. By excluding patients who did not reside in the area at the time of surgery, we attempted to limit the referral bias of potentially more complex cases and limit the potential for loss of long-term follow-up. In addition, patients were censored at the time of the last follow-up, and vital status was queried in the National Death Index. However, there remains the potential for underestimation of events if care occurred at different institutions and was not documented in our records.

An additional limitation to this study, inherent to current clinical practice, is that there are no established criteria for when to intervene on a progressively dysfunctional truncal valve. Although it is generally accepted that left ventricular dilation, ventricular dysfunction, and clinical symptoms are indications for intervention, other factors, such as patient age and surgical options available, play a role in decision making. Therefore, these results reflect institution or provider practices over time.

CONCLUSIONS

In patients with TA, the long-term need for truncal valve intervention remains common. Patients with moderate or worse initial truncal valve regurgitation or stenosis, residual truncal valve regurgitation after initial TA repair, and single coronary ostium are potentially at higher risk for truncal valve intervention. Truncal root *z*-score may be useful to identify which patients are at risk for developing truncal valve dysfunction. These findings can aid in patient counseling and stratify surveillance strategies for this growing patient population.

ARTICLE INFORMATION

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Supplementary Material

Tables S1–S4
Figure S1

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SUPPLEMENTAL MATERIAL

Supplemental Table 1. Causes of death in long-term follow-up (n=27)

Causes of Death	**Number**	**Age at death (months)**
Out of hospital arrest	4	2.0-63.4 mo
Cerebral injury related to truncal valve replacement	1	54.7
Re-operation for residual lesion	1	4.8
Post-catheterization in hospital arrest	1	6.4
Catheterization conduit dilation complication	1	46
Sepsis	2	1.0 mo-19 years
Sequelae related to pulmonary hypertension	1	10.0
Pulmonary vein disease	1	5.4
Sequelae related to volvulus	1	10.8
Sequelae related to lung transplant	1	16.3
Unknown	13	2.5 mo – 30 years

Age range presented when more than one event per category

Table S2. Additional Re-interventions during Follow up of 148 Patients.

Re-intervention event	Number of events	Number of patients (%)
Surgical		
RV-PA conduit replacement	142	95 (64)
PA plasty	52 (47)	47 (32)
RVOT resection	17	17 (11)
Aortic arch reconstruction	4	4 (2)
Ascending aorta reduction	14	14 (9)
Tricuspid or mitral repair	12	12 (8)
Catheterization		
Conduit dilation or stenting	169	107 (72)
Transcatheter pulmonary valve placement	32	36 (24)
LPA dilation or stenting	121	59 (40)
RPA dilation or stenting	163	69 (47)
Aortic arch dilation or stenting	7	5 (3)

PA= pulmonary artery, LPA= left pulmonary artery, RPA= right pulmonary artery, RV- right ventricle, RVOT= right ventricular outflow tract

Table S3. Imaging data prior to truncal valve intervention event - Echocardiographic data.

	N=50
Quantitative left ventricular EF	
≥55%	24
50-55%	6
40-49%	8
30-39%	1
<30	0
Missing data	11
Qualitative left ventricular function	
Normal	38
Mildly depressed	6
Moderately depressed	5
Severely depressed	0
Depressed but not qualified	5
Qualitative left ventricular size	
Normal	4
Mildly dilated	5
Moderately dilated	11
Severely dilated	17
Dilated but not qualified	5
Missing data	6

EF ejection fraction

Table S4. Imaging data prior to truncal valve intervention event - MRI data.

	N=24
Left ventricular EF ≥55% 50-55% 40-49% 30-39% <30	Number of patients 12 7 4 1 0
Left Ventricle EDVi (ml/m2) median (range)	141 (86-257)
Left Ventricle EDVi Z-score median (range)	7.0 (3.5-16.6)

EDVi End diastolic volume indexed to body surface area, EF ejection fraction

Figure S1. Flow chart of Truncus Arteriosus Patients.