Thoracic Aortic, Aortic Valve, and Mitral Valve Surgery in Pediatric and Young Adult Patients With Marfan Syndrome: Characteristics and Outcomes

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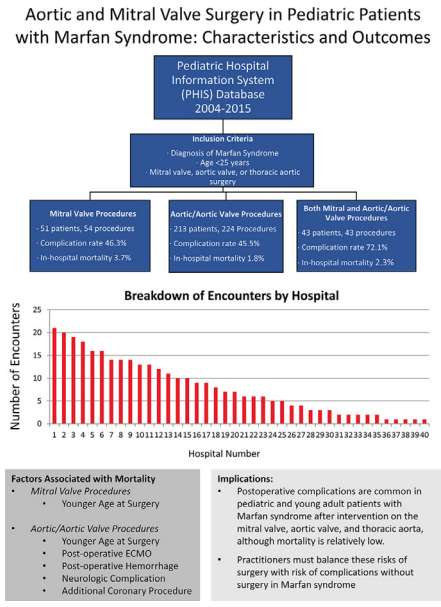
Patients with Marfan syndrome (MFS) often require surgical intervention on the mitral valve (MV), aortic root or valve (AV), or thoracic aorta (TA) during childhood and adolescence. We aim to utilize a national database to evaluate outcomes in pediatric and young adult patients with MFS undergoing MV, AV, and aortic surgical procedures, and describe factors associated with increased mortality. The Pediatric Hospital Information System (PHIS) database, a multi-institutional administrative database of 48 pediatric hospitals, was queried for patients less than 25 years of age with a diagnosis of MFS (ICD-9 759.82) who underwent MV, AV, or thoracic aortic surgery between January 2004 and October 2015. We assessed comorbidities and complications, and performed univariate analysis to evaluate factors associated with inpatient mortality. Included were 321 hospital encounters in 294 patients. Fifty-one patients underwent 54 MV surgeries, 213 patients underwent 224 aortic/AV surgeries, and 43 patients underwent both MV and aortic/AV surgery in the same encounter. Postoperative complications were common for all surgeries (46.3% for MV procedures and 45.5% for aortic/AV procedures). Overall in-hospital mortality was 2.2% (3.7% for MV procedures, 1.8% for AV/aortic procedures, and 2.3% in the combined MV and aortic/AV procedure group). Aortic dissection or rupture was reported in 3.4%, with no in-hospital mortalities. Death after MV as well as after aortic/AV surgery was associated with younger age. Postoperative complications are



Cardiac surgery in children with Marfan syndrome, methodology, results, and implications.

Central Message

Complications are common in pediatric and young adult patients with Marfan syndrome after intervention on the mitral valve, aortic valve, and thoracic aorta, but mortality is relatively low.

Abbreviations: AV, aortic valve; ICD-9, International Classification of Diseases, 9th Revision; MFS, Marfan syndrome; MV, mitral valve; PHIS, Pediatric Hospital Information System; TA, thoracic aorta

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common in pediatric and young adult patients with MFS after intervention on the MV, AV, and TA, although mortality is relatively low.

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Perspective Statement

While outcomes of cardiovascular surgery in patients with Marfan syndrome have been well described in adult populations, comparable data for pediatric patients are limited. We utilized a national database to evaluate cardiovascular surgical outcomes in pediatric and young adult patients with Marfan syndrome. We describe complications, in-hospital mortality, and factors associated with mortality.

INTRODUCTION

Marfan syndrome (MFS) is an autosomal dominantly inherited connective tissue disorder resulting from mutations in the fibrillin-1 gene.[1] MFS is associated with musculoskeletal, cardiac, and ocular pathology, with the most significant morbidity and mortality occurring from cardiovascular complications. The establishment of clinical criteria and improved genetic testing has allowed earlier diagnosis of MFS.[2] Nearly all patients with MFS will develop cardiovascular disease over their lifetimes, most frequently from aortic root enlargement with associated aortic regurgitation, thoracic aortic (TA) aneurysm, aortic dissection, or mitral valve (MV) prolapse.[3] While the majority of patients with MFS do not require cardiovascular surgical intervention until adulthood, the prevalence of surgical cardiovascular disease in childhood and adolescence, particularly in those patients with neonatal Marfan phenotype, is not insignificant. Aortic dissection or rupture has been reported in up to 4.3% of patients with MFS in childhood and adolescence.[4] As such, surgical intervention on the aorta, aortic root or valve, or MV is sometimes necessary during childhood and adolescence.

While outcomes of cardiovascular surgery in patients with MFS have been well described in adult populations,[5–7] comparable data for pediatric patients are more limited,[8–18] consisting primarily of single-center experiences. As MFS is relatively rare, with an estimated prevalence of 1 in 5000–10,000 live births,[1] and the number of patients requiring surgical intervention in childhood or adolescence rarer still, we aimed to utilize a national database to evaluate surgical outcomes in pediatric and young adult patients with MFS undergoing MV, aortic root/valve (AV), and aortic surgical procedures, and describe factors associated with mortality. We hypothesized that patients with MFS undergoing these cardiovascular procedures would have complicated postoperative courses, but low overall in-hospital mortality.

METHODS

Study data were obtained from Pediatric Health Information System (PHIS), an administrative database that contains inpatient, emergency department, ambulatory surgery, and observation encounter-level data from over 48 not-for-profit, tertiary-care pediatric hospitals in the United States.[19] These hospitals are affiliated with the Children's Hospital Association (Lenexa, KS). Data quality and reliability are assured through a joint effort between the Children's Hospital Association and participating hospitals. Portions of the data submission and data quality processes for the PHIS database are managed by Truven Health Analytics (Ann Arbor, MI). For the purposes of external benchmarking, participating hospitals provide discharge/encounter data including demographics, diagnoses, and procedures. Nearly all of these hospitals also submit resource utilization data (eg, pharmaceuticals, imaging, and laboratory) into PHIS. Data are de-identified at the time of data submission, and data are subjected to a number of reliability and validity checks before being included in the database. For this study, data from 40 hospitals were included. This study was considered by the Baylor College of Medicine Institutional Review Board to not constitute human subjects research, and was determined to be exempt from review.

The PHIS database was queried for all patients less than 25 years old with a MFS diagnosis using the International Classification of Diseases, 9th Revision (ICD-9) code 759.82, who underwent MV, aortic root or valve, or TA surgery between January 2004 and October 2015. ICD-9 procedure codes are presented in Supplementary Appendix 1. The cutoff of 25 years was chosen as young adult patients receiving care at pediatric institutions may reasonably still be followed by, and have surgical procedures performed at, pediatric institutions at this age.

Covariates including age at surgery, sex, and race/ethnicity were obtained for each patient. Coexisting diagnoses, complications, and additional procedures performed during the same admission were assessed using ICD-9 diagnosis and procedure codes (Supplementary Appendix 1). Due to limitations of the PHIS database, relative timing of diagnostic codes is not available. For the purposes of this analysis, diagnoses of cardiomyopathy, heart failure, aortic dissection, aortic aneurysm, or aortic rupture were considered to be present in the preoperative period if reported. Diagnoses of arrhythmia were considered to be postoperative complications. Other codes were considered to be present in the postoperative period.

The MV, AV, or TA procedure was treated as the index procedure for each hospital encounter. Additional procedures were indexed by adjusted day of surgery to this cardiac procedure to determine relative timing. The primary outcome was in-hospital mortality.

Statistical Analysis

Patient encounters were stratified for statistical evaluation: (1) intervention involving the MV, (2) intervention involving the TA or AV, and (3) intervention involving both the MV and the TA/AV during the same procedure. The number of cases performed at each hospital was reported. Patients were analyzed by age in 3 groups: <2 years, 2–12 years, and >12 years,

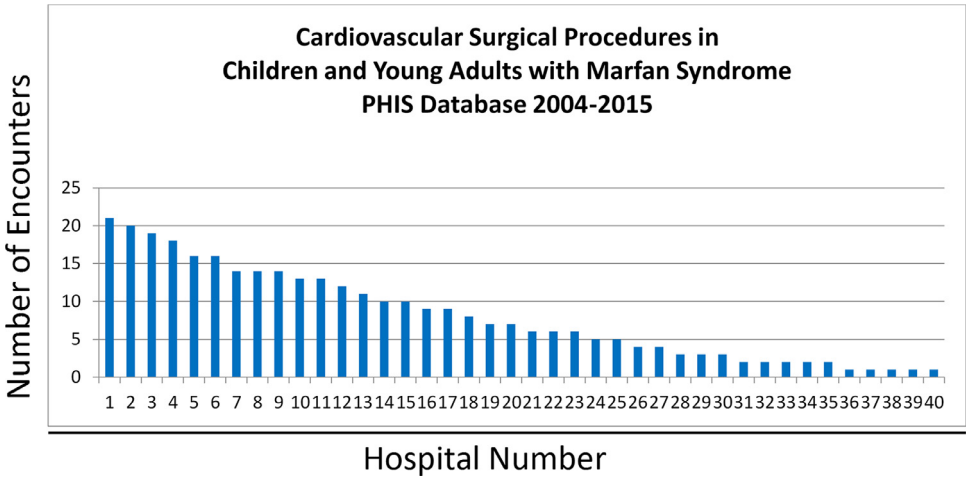

Figure 1. Total combined mitral valve, aortic valve, and aortic surgeries in children with a diagnosis of Marfan syndrome in the Pediatric Hospital Information System (PHIS) database between January 2004 and October 2015, by hospital.

in an attempt to reflect those with neonatal Marfan phenotype, prepubertal children, and pubertal/postpubertal patients.

Categorical and continuous variables were compared using chi-squared, Fisher's exact and nonparametric tests as appropriate. Given the low number of outcomes, the sample was too small to perform mixed (to account for hospital clustering) or multivariate analyses. The relationship between hospital surgical volume and mortality was evaluated using Spearman correlation. Significance was defined as P value <0.05. IBM SPSS Statistics 24.0 was utilized for statistical analysis.

RESULTS

Forty hospitals reported at least 1 case during the study period (Fig. 1). Overall, 321 hospital encounters in 294 patients were evaluated. Fifty-one patients underwent 54 isolated MV surgeries and 213 patients underwent 224 aortic/AV surgeries. In 43 cases, the patient underwent MV and aortic/AV surgery in the same hospitalization.

Median age at MV surgery was younger than at aortic/AV surgery (10.6 years vs 16.2 years), and patients undergoing MV surgery were more likely to have associated heart failure (27.8% vs 8.9%, Table 1). Aortic dissection or rupture was reported in 11 patients (3.4%), with a mean age of 16.5 years (range 13.6–20.2). Seven (64%) had TA dissection reported, and 4 (36%) had unspecified site of aortic dissection. One had both thoracic and abdominal aortic dissections reported, and 1 patient had both abdominal aortic dissection and aortic dissection of unspecified site reported. No patient with aortic dissection/rupture died.

Mortality

Seven patients died, for an overall hospital mortality rate of 2.2% (3.7% in the MV procedure group, 1.8% in the aortic/AV procedure group, and 2.3% in the combined MV and aortic/AV procedure group, Table 2). Specific characteristics for each mortality are listed in Supplementary Appendix 2. There was 1 death in the group of patients undergoing both mitral and aortic/AV surgery during the same encounter. Five centers reported 1 mortality, and 1 center reported 2 mortalities. Given the low mortality rate, correlation with case volume could not be meaningfully evaluated.

Complications

Postoperative complications were common for all surgeries and were reported in 49.2% of encounters in the overall sample (Tables 2–4). The most frequently reported complications were arrhythmia, postoperative hemorrhage, pericardial complications, and respiratory complications.

Factors Associated With Mortality

By univariate analysis, sex and race/ethnicity were not associated with mortality in any group (Tables 5 and 6). In the MV surgery group, patients who died were younger those than survivors (median 1.3 vs 10.9 years, respectively), at the borderline of statistical significance (P = 0.05). Younger age at surgery was also associated with death after aortic/AV surgery (median age 10.3 in those that died vs 16.3 years in survivors, P = 0.02, Table 6). Intermediate outcomes associated with death after aortic/AV surgery were postoperative use of ECMO, postoperative hemorrhage, any neurologic complication, and additional coronary artery procedure (Table 6).

DISCUSSION

This study, to our knowledge, represents the first use of a US national database to describe postoperative outcomes in pediatric and young adult patients with MFS undergoing surgical intervention on the MV, AV, or TA during childhood, adolescent, and early adult years. Our data also highlight the relative rarity of surgical intervention in pediatric and young adult patients with MFS on the MV, AV, or TA in pediatric facilities. No center in our sample had performed more than 21 procedures over the 11-year period. It is likely that many cases, particularly in adolescents and young adults, are being referred to adult hospitals with greater surgical volume and experience with these procedures. In a report of aortic operations in 300 patients

Table 1. Characteristics of Sample Population

Variable		Results
Mitral valve procedures		
Total encounters		54
Unique patients		51
Age (y)		10.6 (0.4–22.5)
Sex	Male	26 (48.1)
	Female	28(51.9)
Race/ethnicity	Non-Hispanic White	35 (64.8)
	Non-Hispanic Black	6 (11.1)
	Hispanic	5 (9.3)
	Other/unknown	8 (14.8)
Heart failure		15 (27.8)
Aortic valve/aortic procedures		
Total encounters		224
Unique patients		213
Age (y)		16.2 (0.1–24.3)
Sex	Male	174 (77.7)
	Female	50 (22.3)
Race/ethnicity	Non-Hispanic White	134 (59.8)
	Non-Hispanic Black	28 (12.5)
	Hispanic	36 (16.1)
	Other/Unknown	26 (11.7)
Aortic dissection or rupture		11 (4.9)
Heart failure		20 (8.9)
Both MV and AV/aortic procedures in same encounter		
Total encounters		43
Unique patients		43
Age (y)		11.9 (1.0–23.4)
Sex	Male	29 (67.4)
	Female	14 (32.6)
Race/ethnicity	Non-Hispanic White	23 (53.4)
	Non-Hispanic Black	5 (11.6)
	Hispanic	8 (18.6)
	Other/unknown	7 (16.2)
Aortic dissection or rupture		0 (0)
Heart failure		7 (16.2)

Results are presented as median (range) or *n* (%). Percentages do not add to 100 due to rounding.

with confirmed or suspected MFS performed at an adult hospital, the youngest patient was 11 years old and the mean age was 39 years.[5] While detailed analysis of this finding is beyond the scope of this manuscript, it is notable that mortality rates are low despite this case distribution. However, it is possible that the high rate of complications described in this study might be lower had these patients received care at a center with a more robust experience in the cardiovascular care of patients with MFS.

Nearly equal numbers of males and females underwent MV procedures, but in patients undergoing aortic/AV procedures, the majority were males. Sex-related differences have been previously reported in adults with MFS, with men having higher rates of prophylactic aortic root surgery and aortic dissection.[20,21] In contrast, rates of MV surgery reported in adult males and females with MFS are similar. Our data therefore are comparable to this trend in adults.

We found that postoperative complications were common in these patients, but overall in-hospital mortality rates in pediatric and young adult patients with MFS were relatively low. This mortality rate is in keeping with single-center studies in the pediatric and young adult population that report mortality estimates ranging from 0% to 7.1%.[8–18] Adult studies from a similar period have reported mortality in the 0–1.5% range for elective aortic root replacements, with mortality as high as 4.4–11.7% in urgent/emergent situations.[22–24] Although the PHIS database does not detail the relative urgency with which surgical interventions are performed, our sample likely contains patients throughout the spectrum of disease severity, which may account for some of the increased mortality observed compared to adult populations. However, most emergent operations are for dissection or rupture, and the fact that no patients in this sample with aortic dissection or rupture died argues against this point. There is also likely additional complexity in performing these interventions in children.

We found that younger age at time of surgical intervention was associated with mortality. This could suggest a benefit in delaying surgical intervention on younger patients, but likely represents increased severity of disease in these patients, with earlier progression of cardiovascular disease and requirement for earlier surgical intervention. Some of these patients may have neonatal MFS phenotype,[25] who would be more high-risk operative candidates. Further analysis in patients with documented neonatal MFS would be of benefit in better ascertaining their operative risk in comparison to those with typical disease progression.

The diagnosis of heart failure was seen more frequently in individuals undergoing MV intervention, and this may have been a driving factor for surgical intervention during childhood and adolescence. While we cannot assess relative timing of heart failure diagnosis in these patients, nor indications for surgery, due to limitations of PHIS, it may be that a pre-existing diagnosis of heart failure leads these patients to be in poorer condition prior to operative intervention, and thus at higher operative risk. These patients may represent individuals with neonatal MFS, a rare form of the disease with early onset and a severe phenotype with high mortality,[25] typically secondary to significant heart failure symptoms in infancy and early childhood. Given the grave prognosis these children face, operative intervention early in life may be the only viable option, and teams and families accept an increased mortality risk with these procedures. However, postoperative ventricular dysfunction in patients with MFS is a well-recognized phenomenon, and the high rate of heart failure may also be due to this development.

Postoperative hemorrhage was significantly associated with mortality in patients undergoing aortic/AV surgeries. It is likely that many of these were early cases of bleeding related to technical issues; however, it is possible that these patients were on anticoagulation prior to intervention, or were more aggressively anticoagulated after their procedures. We did not have access to detailed information regarding anticoagulation regimens in these patients. Of note, there was no correlation between mechanical valve replacement and postoperative hemorrhage.

Table 2. Procedure Characteristics and Complications in Patients With Marfan Syndrome Under 25 Years of Age (PHIS Database 2004–2015)

	n (%)	Any Complication* *n* (%)	In-Hospital Mortality *n* (%)
All encounters	321	158 (49.2)	7 (2.2)
Mitral valve procedures	54	25 (46.3)	2 (3.7)
Mitral valvuloplasty	36 (66.7)	14 (38.8)	2 (5.6)
MV replacement, tissue	2 (3.7)	2 (100.0)	0 (0)
MV replacement, mechanical	16 (29.6)	9 (56.3)	0 (0)
Aortic valve/aortic procedures	224	102 (45.5)	4 (1.8)
Aortic valvuloplasty, no reported thoracic aortic intervention	11 (4.9)	6 (54.5)	0 (0)
AV replacement, tissue, no reported TA surgery	16 (7.1)	10 (62.5)	0 (0)
AV replacement, mechanical, no reported TA surgery	62 (27.7)	29 (46.8)	0 (0)
Aortic valvuloplasty and TA surgery	28 (12.5)	9 (32.1)	0 (0)
AV replacement, tissue, and TA surgery	5 (2.2)	2 (40.0)	0 (0)
AV replacement, mechanical, and TA surgery	20 (8.9)	10 (50.0)	1 (5.0)
TA surgery without AV surgery	82 (36.6)	36 (43.9)	3 (3.7)
Both MV and aortic/AV procedure in same encounter	43	31 (72.1)	1 (2.3)

*Complications include bleeding, shock, stroke/intracranial hemorrhage, mechanical support, delayed sternal closure, arrhythmia, pacemaker or AICD placement, cardiac arrest, kidney injury, wound complications, postoperative infection, GI complications, respiratory complications, device/graft malfunction, and in-hospital mortality.

Table 3. Complications in Patients With Marfan Syndrome Undergoing Mitral Valve Procedures (*n* = 54)

Complication*	*n* (%)
Arrhythmia	25 (27.8)
Pericardial complication	6 (11.1)
Respiratory complication	4 (7.4)
Postoperative hemorrhage	4 (7.4)
Device/graft complication	3 (5.6)
Shock	2 (3.7)
Neurologic complication	2 (3.7)
Postoperative ECMO	2 (3.7)
Postoperative tracheostomy	2 (3.7)

ECMO, extracorporeal membrane oxygenation.
*Grouping of complications and comorbidities as outlined in Supplementary Appendix 1. All complications and comorbidities with ≥2 incidences are reported.

Table 4. Complications in Patients With Marfan Syndrome Undergoing Aortic Valve/Aortic Procedures (*n* = 224)

Complication*	*n* (%)
Any arrhythmia	45 (20.1)
Postoperative hemorrhage	33 (14.7)
Pericardial complication	25 (11.2)
Device/graft complication	19 (8.5)
Respiratory complication	17 (7.6)
Delayed chest closure	8 (3.6)
Coronary procedure	6 (2.7)
Neurologic complication	6 (2.7)
Pacemaker placement	6 (2.7)
Shock	5 (2.2)
Postoperative ECMO	4 (1.8)
Acute kidney injury	4 (1.8)

ECMO, extracorporeal membrane oxygenation.
*Grouping of complications and comorbidities as outlined in Supplementary Appendix 1. All complications and comorbidities with ≥1.5% incidence are reported.

All patients in the isolated aortic/AV surgery group requiring postoperative ECMO died. Some patients with MFS can likely be successfully supported with ECMO postoperatively, including 1 in our MV procedure group. The small number of mortalities and size of the dataset limits ability to draw conclusions regarding the merits of ECMO support in these patients.

Eleven patients had reported diagnoses of aortic dissection or rupture, highlighting that although children have a lower rate of dissection compared to adults, there is a clinically significant burden of disease in this population. No individuals with a diagnosis of aortic dissection or rupture died, though this must be interpreted in the context of several limitations. First, all patients had to carry a cardiac surgical code, which means any patient with aortic dissection leading to death prior to attempted surgical intervention would not be included. Second, as all patients required a diagnostic code for MFS to be included, one can infer that most individuals were already aware of their MFS diagnosis prior to presenting for surgical intervention. Prior data have demonstrated that patients with a MFS diagnosis have decreased time from symptom onset to diagnosis of aortic dissection.[26] Awareness of MFS diagnosis has been postulated to be a significant factor in improving outcomes in patients with aortic dissection, and thus is likely to influence their clinical course when presenting with severe complications such as aortic dissection or rupture.

As in many cases these procedures are being performed to prevent further cardiovascular complications, such as aortic dissection, a low mortality rate should be expected. Previous data have suggested an aortic event rate of dissection or death between 0.5% and 4.5% over a 3-year period in predominantly adult populations of patients with MFS.[27,28] While comparable

Table 5. Univariate Analysis of Factors Associated With In-Hospital Mortality in Mitral Valve Procedures

Variable	Survived $n = 52$	Died $n = 2$	*P* Value
Demographics/ coexisting diagnoses	*n* (%) or median (range)	*n* (%) or median (range)	
Sex			1.0
Female	27 (52)	1 (50)	
Male	25 (48)	1 (50)	
Race/ethnicity			0.78
Hispanic	5 (10)	0 (0)	
Non-Hispanic Black	6 (12)	0 (0)	
Non-Hispanic White	33 (64)	2 (100)	
Other/unknown	8 (15)	0 (0)	
Age at surgery in years (continuous)	10.9 (0.4–22.5)	1.3 (0.4–2.3)	0.05
Age at surgery (categorical)			0.38
<2 years	9 (17)	1 (50)	
2–12 years	22 (42)	1 (50)	
>12 years	21 (40)	0 (0)	
Heart failure	13 (25)	2 (100)	0.07
Intermediate outcomes			
Postoperative ECMO	1 (1.9)	1 (50)	0.07
Postoperative tracheostomy	1 (1.9)	1 (50)	0.07
Device/graft complication	2 (3.8)	1 (50)	0.11
Postoperative hemorrhage	3 (5.8)	1 (50)	0.14
Respiratory complication	3 (5.8)	1 (50)	0.14
Arrhythmia	14 (26.9)	1 (50)	0.48
Pericardial complication	6 (11.5)	0 (0)	1.0
Shock	2 (3.8)	0 (0)	1.0
Neurologic complication	2 (3.8)	0 (0)	1.0

Table 6. Univariate Analysis of Factors Associated With In-Hospital Mortality in Aortic/Aortic Valve Procedures

Variable	Survived $n = 220$	Died $n = 4$	*P* Value
Demographics/ coexisting diagnoses	*n* (%) or median (range)	*n* (%) or median (range)	
Sex			1.0
Female	49 (22)	1 (25)	
Male	171 (78)	3 (75)	
Race/ethnicity			0.62
Hispanic	36 (16)	0 (0)	
Non-Hispanic Black	27 (12)	1 (25)	
Non-Hispanic White	131 (60)	3 (75)	
Other/unknown	26 (12)	0 (0)	
Age at surgery in years (continuous)	16.3 (0.1–24.6)	10.3 (5.3–14.6)	0.02
Age at surgery (categorical)			0.11
<2 years	4 (1.8)	0 (0)	
2–12 years	29 (13)	2 (50)	
>12 years	187 (85)	2 (50)	
Heart failure	19 (8.6)	1 (25)	0.31
Aortic dissection or rupture	11 (5.0)	0 (0)	1.0
Intermediate outcomes			
Postoperative ECMO	0 (0)	4 (100)	<0.001
Coronary procedure	4 (1.8)	2 (50)	0.004
Neurologic complication	4 (1.8)	2 (50)	0.004
Postoperative hemorrhage	30 (13.6)	3 (75)	0.011
Acute kidney injury	3 (1.4)	1 (25)	0.07
Arrhythmia	43 (19.5)	2 (50)	0.18
Respiratory complication	16 (7.3)	1 (25)	0.27
Device/graft complication	18 (8.2)	1 (25)	0.30
Delayed chest closure	8 (3.6)	0 (0)	1.0
Pericardial complication	25 (11.4)	0 (0)	1.0
Pacemaker placement	6 (2.7)	0 (0)	1.0
Shock	5 (2.3)	0 (0)	1.0

event rates for pediatric populations are not readily available, it can be assumed to be lower than the adult population, when one excludes cases with severe phenotypes and high mortality risk seen in neonatal MFS. Any surgical intervention with a primary goal of preventing subsequent aortic dissection or death should have a mortality rate that is at a minimum lower than the expected mortality risk in patients who have not undergone surgery. Given our finding of 2.2% overall in-hospital mortality in this population, the risk of complication and operative mortality in children and young adults should be carefully considered before recommending intervention.

Limitations

Study limitations include that diagnoses and procedures reported are only as documented in the medical record using ICD-9 codes. PHIS does not provide the ability to confirm diagnoses of MFS using established criteria, and thus, some patients coded as having MFS may actually have another connective tissue disorder, or not meet established MFS diagnostic criteria. It is also possible that some patients who carry a MFS diagnosis were not coded as such at the time of their hospital encounter, and thus inappropriately excluded.

Additionally, the number of isolated AV procedures in this series was higher than expected, as the standard surgical approach anticipated for most of these cases would involve aortic root replacement. This may represent under-coding in the sample, and prompted analysis of the entire block of aortic and AV interventions together, rather than as isolated procedures, recognizing that the true number of aortic root-replacing procedures may be under-reported. Unfortunately, procedural codes available through PHIS do not allow determination of the specific procedure performed, so we cannot comment on relative outcomes in valve-sparing and valve-replacing procedures, or on variations in aortic root replacement techniques. Similarly, the TA surgery group includes proximal aortic operations (root, ascending, arch) and distal aortic procedures (descending thoracic and thoracoabdominal), operations that have very different outcome profiles.

Data interpretation is also limited by inability to determine the relative timing of coexisting diagnostic codes in relation to surgical interventions. While we are able to assess the relative time course of additional procedures to the index cardiac surgical intervention, PHIS does not provide equivalent information regarding the timing of diagnoses. Additionally, as PHIS only provides information regarding in-hospital mortality, we cannot assess mortality after discharge. Because of the low number of deaths, we were unable to perform multivariate analysis to identify independent predictors of mortality.

Despite limitations, this study uses a nationally representative sample of patients with MFS to provide an estimate of mortality associated with cardiovascular interventions commonly required during the pediatric and young adult years, and is the largest study to date in this population. While these patients may have complicated postoperative courses, their overall mortality is relatively low (Graphical Abstract). Further analysis regarding long-term morbidity and mortality would be beneficial in informing appropriate surgical timing and prognosis.

SUPPLEMENTARY MATERIAL

The following is the supplementary data to this article:

COMPLICATIONS, COMORBIDITIES AND MORTALITY (AORTIC VALVE/THORACIC AORTIC PROCEDURES)

	n (%)	Any Complication/ Comorbidity (%)	In-Hospital Mortality (%)
Aortic Valve/Aortic Procedures	224	102(45.5)	4(1.8)
Aortic valvuloplasty, no reported thoracic aortic intervention	11(4.9)	6(54.5)	0(0)
AV replacement, tissue, no reported TA surgery	16(7.1)	10(62.5)	0(0)
AV replacement, mechanical, no reported TA surgery	62(27.7)	29(46.8)	0(0)
Aortic valvuloplasty and TA surgery	28(12.5)	9(32.1)	0(0)
AV replacement, tissue, and TA surgery	5(2.2)	2(40.0)	0(0)
AV replacement, mechanical, and TA surgery	20(8.9)	10(50.0)	1(5.0)
TA surgery without AV surgery	82(36.6)	36(43.9)	3(3.7)

Video 1. This video summarizes the methodology, results, and implications of our study examining the characteristics and outcomes of cardiovascular surgical interventions in pediatric and young adult patients with Marfan syndrome.

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