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Safety and Efficacy of Surgical and Percutaneous Cardiac Interventions for Adults With Down Syndrome

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Abstract

Objective: To assess risks and benefits of cardiac intervention in adults with Down syndrome (DS).

Patients and Methods: A retrospective review was conducted using data from a study we published in 2010. Patients aged 18 years or older with DS who underwent cardiac operation or percutaneous intervention from February 2009 through April 2022 (new cohort) were compared with patients in the previous study (January 1969 through November 2007; remote cohort) at Mayo Clinic.

Results: In total, 81 adults (43 men; 38 women) with DS underwent 89 cardiac interventions (84 surgical; 5 percutaneous) at a mean age of 33 years. Twenty-six patients presented with complete atrioventricular canal defect (17%) or tetralogy of Fallot (15%). The most common adult procedures were valve interventions: mitral (31%), tricuspid (15%), and pulmonary (12%). Of pulmonary valve interventions in the new cohort, 33% were performed percutaneously. The postoperative mortality rate was low (1% total). The mean time between last operation and death was 16 years.

Conclusion: Adults with DS can undergo cardiac operation and percutaneous intervention with low morbidity and mortality risk and good long-term survival.

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Down syndrome (DS) is the most common chromosomal disorder, occurring in 1 in every 700 births.[1] The number of infants born with DS has increased by ∼30% over the past 25 years, likely related to older maternal age (>35 years).[1,2] Approximately 50% of all infants with DS also experience a congenital heart defect, the most common being endocardial cushion defects.[1,3] Persons with DS and other congenital heart defects are surviving longer—many into adulthood—thanks to advancements in diagnostic testing, stabilization techniques, and early surgical and/or percutaneous intervention.[4] Many adults with congenital heart disease will require cardiac intervention or reintervention. One study evaluating adults with congenital heart disease found that approximately one-fifth required cardiovascular operation during a 15-year period, with 40% of procedures being reoperations.[5] The mean age at cardiac operation (initial operation and reoperations) was between 40 and 49 years, and the mean age at cardiac percutaneous intervention was 42 years.[5]

Patients with DS have a higher-than-average prevalence of comorbid conditions such as obstructive sleep apnea (50%-75%), thyroid disease (4%-18%), and anemia (3%-10%).[1] They are also at higher risk for Alzheimer-type dementia and have a lower life expectancy than people without DS.[1] According to the Centers for Disease Control and Prevention, the mean life expectancy of persons with DS is about 47 years, although it is reported at approximately 60 years in high-income countries.[1,2] The primary causes of death are respiratory tract infections and complications of congenital heart disease.[6]

Research has focused on the safety and effectiveness of cardiac operation in the pediatric population with DS.[7-9] Studies in adults are limited. At least 2 studies found no difference in mortality risk between patients with and without DS undergoing cardiac operation in both childhood and adulthood, but data regarding morbidity risk specifically for the DS population are limited.[3,10] Because of improved safety and effectiveness, catheter-based interventions are now preferred over operation at some medical centers,[11] although the effectiveness of these procedures for persons with DS are also limited. This study is a comprehensive update of a previous study completed at our institution in which the safety of cardiac operation was evaluated for adults with DS.[12] This updated study provides new data regarding percutaneous cardiac intervention. In addition, long-term outcomes and patterns regarding cardiac interventions were assessed across multiple decades (1969-2022) for persons with DS.

PATIENTS AND METHODS

We conducted a retrospective review and updated data from a 2010 study of procedures for adults with DS.[12] The Mayo Clinic Institutional Review Board deemed the study exempt from the requirement for approval and informed consent.

Patients

Patients with DS older than 18 years who underwent cardiac operation or percutaneous intervention from February 2009 through April 2022 (new cohort) at any Mayo Clinic site were compared with those assessed in the previous study (January 1969 through November 2007; remote cohort) by using adult congenital, interventional, and surgical institutional databases. A focused update on long-term clinical outcomes of patients included in the previous study was also performed.

Data Analysis

Differences in postinterventional (or postoperative) complications were compared between the remote and new cohorts. Associations between preoperative comorbid conditions and length of stay were analyzed by using data from both cohorts. Differences in continuous outcomes were tested with Wilcoxon rank sum tests; differences in categorical variables were tested with Fisher exact tests. Spearman correlation coefficients were estimated to assess the relationships between the number of childhood operations and the length of hospital stay and duration of ventilator therapy. Statistical analyses was performed with SAS, version 9.4 (SAS Institute). Significance was considered at $P<.05$.

RESULTS

In total, 81 adults (43 men, 38 women) with DS underwent 89 cardiac interventions (84 surgical, 5 percutaneous). Table 1 summarizes characteristics of both cohorts. Of the 81 patients, 14 (17%) presented with complete atrioventricular (AV) canal defect and 12 (15%) with tetralogy of Fallot (TOF). At adult intervention, the mean age of the patients was 31.9 years (including reoperations), with a range from 18 to 58 years. Cardiac diagnoses from childhood are summarized in Table 2.

Past Pediatric Operations

Thirty-six patients (44%) had undergone a previous operation in childhood. The prevalence of childhood operations was 69% (22/32) in the new cohort and 29% (14/49) in the remote cohort (Table 1). No significant difference was found in the mean age at first childhood operation between the 2 cohorts ($P=.83$). Of the 4 patients with TOF in the remote cohort, none underwent operation in childhood. Of the 8 patients with TOF in the new cohort, 7 underwent complete TOF repair in childhood; 1 had a palliative Blalock-Thomas-Taussig shunt and a Waterston shunt. Two patients (aged 15 and 17 years) underwent heart transplant because of genetically caused dilated cardiomyopathy. One of the patients who underwent cardiac transplant died 2 years later after undergoing a routine cardiac biopsy. The other patient was alive and doing well 16 years after transplant.

Adult Procedures: New Cohort

Patients' comorbid conditions before their adult cardiac procedures are summarized in Table 3 and are described in greater detail in the publication of the previous study results

TABLE 1. Demographic and Clinical Characteristics of Remote and New Cohorts With Down Syndrome

Characteristic	Remote cohort (n=49)	New cohort (n=32)	Total (N=81)
Sex, n (%)			
Men	26 (53)	17 (53)	43 (53)
Women	23 (47)	15 (47)	38 (47)
Date of adult operation	January 1969–November 2007	February 2009–April 2022	January 1969–April 2022
Patients with previous pediatric operations, n (%); No. of pediatric operations	14 (29); 22	22 (69); 35	36 (44); 57
Age at first adult operation, mean (SD; range), y[a]	32.4 (10.4; 18-58)	30.9 (10.5; 18-55)	31.9 (10.3; 18-58)
Total procedures, n (including reoperations)	55	34[b]	89
Reoperations, n	6[c]	2[d]	8

[a]Includes second operations.
[b]Consisted of 29 open heart surgical procedures and 5 percutaneous procedures.
[c]One procedure occurred during the same admission for periprosthetic pulmonary regurgitation; 1 was a third procedure.
[d]All procedures were open heart operation.

for the remote cohort.[12] The following descriptive results pertain to the new cohort.

At adult cardiac intervention, all but 2 of the 32 patients in the new cohort had a preserved left ventricular systolic function of 50% or greater (mean ejection fraction, 60%). In this cohort, 60% of patients (n=19) found normal to mildly reduced right ventricular systolic function and an elevated estimated right ventricular systolic pressure (≥35 mm Hg) on Doppler echocardiography. Four patients recorded estimated right ventricular systolic pressures greater than 45 mm Hg (Table 3), 2 of whom had not had the defect corrected in childhood (1 ventricular septal defect and 1 partial AV canal defect). The other 2 patients underwent surgical correction in childhood (complete AV canal repair and TOF repair—the latter being undertaken at an older age than for other patients with the same diagnosis). Nearly 80% of the patients (n=25) had a body mass index greater than 25 kg/m^2 (mean body mass index, 29.2 kg/m^2). Some patients exhibited additional components of metabolic syndrome: 1, hypertension; 5, hyperlipidemia. Most patients had

TABLE 2. Cardiac Congenital Diseases Diagnosed in Childhood

Condition	Patients, n (%)		
	Remote cohort (n=49)	New cohort (n=32)	Total (N=81)
ASD (isolated)	4 (8)	2 (6)	6 (7)
VSD	6 (12)	2 (6)	8 (10)
AV canal defect			
Partial	1 (2)	5 (16)	6 (7)
Complete	5 (10)	9 (28)	14 (17)
TOF	4 (8)	8 (25)	12 (15)
Bicuspid aortic valve	2 (4)	2 (6)	4 (5)
PDA	1 (2)	3 (9)	4 (5)
Subaortic obstruction	1 (2)	2 (6)	3 (4)
Dilated cardiomyopathy	0 (0)	2 (6)[a]	2 (2)

[a]Both required cardiac transplant.
ASD, atrial septal defect; AV, atrioventricular; PDA, patent ductus arteriosus; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

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TABLE 3. Preoperative Adult Diagnoses and Echocardiographic Data

Preoperative data	Patients, n (%)		
	Remote cohort (n=49)	New cohort (n=32)	Total (N=81)
BMI, mean (range)	NA[a] (21-44)	29.2 (16-40)	NA (16-44)
Diagnosis			
Atrial arrhythmia	1 (2)	5 (16)	6 (7)
CAD	0 (0)	1 (3)	1 (1)
Hypertension	0 (0)	2 (6)	2 (2)
Hyperlipidemia	2 (4)	5 (16)	7 (9)
Diabetes	3 (6)	1 (3)	4 (5)
Anemia (Hb < 12 g/dL)	1 (2)	3 (9)	4 (5)
Seizure disorder	6 (12)	0 (0)	6 (7)
Depression	2 (4)	0 (0)	2 (2)
Obstructive hydrocephalus	1 (2)	0 (0)	1 (1)
Hypothyroidism	14 (29)	12 (38)	26 (32)
OSA	8 (16)	14 (44)	22 (27)
CVA/TIA related to endocarditis	0 (0)	3 (9)	3 (4)
Endocarditis	0 (0)	4 (13)	4 (5)
Status after PPM implantation	1 (2)	4 (13)	5 (6)
PAH	0 (0)	2 (6)	2 (2)
Acute fluid retention[b]	0 (0)	2 (6)	2 (2)
Frequent pneumonia	0 (0)	2 (6)	2 (2)
Creatinine ≥ 1.5 mg/dL (CKD)	7 (14)	3 (9)	10 (12)
Echocardiographic data			
LVEF			
≥50%	42 (86)	23 (72)	65 (80)
<50%	3 (6)	2 (6)	5 (6)
Not reported	4 (8)	7 (22)	11 (14)
RV function			
Normal	31 (63)	12 (38)	43 (53)
Mild dysfunction	9 (18)	7 (22)	16 (20)
Moderate dysfunction	1 (2)	4 (13)	5 (6)
Severe dysfunction	0 (0)	2 (6)	2 (2)
Not reported	8 (16)	7 (22)	15 (19)
RVSP, mm Hg			
<35	9 (18)	10 (31)	19 (23)
35-45	14 (29)	5 (16)	19 (23)
>45	20 (41)	6 (19)	26 (32)
Not reported	6 (12)	11 (34)	17 (21)

[a]NA is reported because only the range was included in the previous study article. Attempts to retrieve mean data proved futile owing to a change in the electronic health record system.

[b]Diagnosed as acute heart failure.

BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CAD, coronary artery disease; CKD, chronic kidney disease; CVA/TIA, cerebrovascular accident/transient ischemic attack; Hb, hemoglobin; LVEF, left ventricular ejection fraction; NA, not available; OSA, obstructive sleep apnea; PAH, pulmonary arterial hypertension; PPM, permanent pacemaker; RV, right ventricular; RVSP, right ventricular systolic pressure.

normal kidney function at operation (mean serum creatinine level, 1.0 mg/dL; range, 0.6-5.0 mg/dL), although 1 patient was undergoing long-term hemodialysis. That patient underwent a complete AV canal repair late in childhood. Four patients had baseline anemia with hemoglobin levels less than 12 g/dL (reference range, 11.6-15.0 g/dL). The most common comorbid conditions were obstructive sleep apnea (44%) and hypothyroidism (38%) (Table 3).

For both groups, the most common adult procedures were valve interventions (combining repairs and replacements) as

TABLE 4. Adult Cardiac Procedures by Cohort

Procedure	Patients, n		
	Remote cohort (n=49)[a]	New cohort (average age at operation, y) (n=32)	Total (N=81)[a,b]
Repair of partial AV canal defect	3	2 (35)	5
MVR	6	8 (24): 1 bioprosthetic, 7 mechanical	14
TAVR	0	1 (50)	1
Subaortic membrane resection	1	4 (29)	5
AVR	7	2 (27): 1 bioprosthetic, 1 mechanical	9
PVR, noninvasive	0	3 (23)	3
PVR, surgical	1	6 (23y)	7
TVR	3	1 (22)	4
Tricuspid valve pannus removal	0	1 (32)	1
Mitral valve repair	7	4 (28)	11
Tricuspid valve repair	2	5 (35)	7
Pericardectomy	0	1 (55)	1
CABG	0	1 (54)	1
Aorta repair/replacement	1	2 (29)	3
Infundibular RVOT resection and patch	0	1 (33)	1
VSD closure	7	3 (32.3)	10
ASD closure	15	2 (27.0)	17
TOF repair	4	0[a]	4

[a]Mean age was not available.

[b]The discrepancy between the number of procedures performed listed in this table and the number of open heart operations listed in Table 1 is related to simultaneous completion of several interventions at 1 time during open heart procedures.

ASD, atrial septal defect; AV, atrioventricular; AVR, aortic valve replacement; CABG, coronary artery bypass graft; MVR, mitral valve replacement; PVR, pulmonary valve replacement; RVOT, right ventricular outflow tract; TAVR, transcatheter aortic valve replacement; TOF, tetralogy of Fallot; TVR, tricuspid valve replacement; VSD, ventricular septal defect.

follows: mitral (31%, n=25), tricuspid (15%, n=12), and pulmonary (12%, n=10). In the new cohort, 33% of pulmonary valve interventions (3/9) were performed percutaneously (mean age, 22.7 years) (Table 4). One procedure was a valve-in-valve transcatheter pulmonary valve replacement (TPVR) with a 26-mm Sapien 3 Ultra tissue prothesis (Edwards Lifesciences), 1 was a valve-in-valve TPVR with a 22-mm Melody valve (Medtronic), and 1 was post-TPVR with a 21-mm Melody valve. Twenty-nine patients underwent open heart operation, with 2 patients undergoing a second cardiac operation procedure thereafter. Five patients underwent percutaneous intervention, 2 of whom had underwent open heart cardiac operation previously.

The mean length of hospital stay for percutaneous intervention in the new cohort was 1 day (range, 1-2 days), and no patients experienced immediate postoperative complications. Endocarditis developed in 1 patient 2 years after percutaneous pulmonary valve replacement with a Melody valve and was managed medically, who was admitted, at the time of writing, approximately 12 years after procedure for severe pulmonary valve regurgitation and mild pulmonary stenosis; moderate mitral valve regurgitation was monitored and managed medically. This patient was asymptomatic at the last follow-up visit in December 2021. The other patient who underwent percutaneous pulmonary valve replacement was well 5 years postoperatively, with only mild pulmonary stenosis on the previous echocardiographic study. The patient who underwent transcatheter aortic valve replacement is doing well approximately 4 years after

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TABLE 5. Postoperative Course and Complications by Cohort

Parameter	Remote cohort (n=49)	New cohort (n=32)[a]	*P*
Duration of ventilator therapy, d[b]			.08[c]
Median (IQR)	1 (1-2)	1 (0-1)	
Range	0-32	0-3	
Length of hospital stay, d			.004[c]
Median (IQR)	8 (7-11)	6 (4-9)	
Range	0-50	0-62	
Postoperative complication, n (%)			
Acute fluid retention[d]	3 (6)	6 (19)	.14[e]
Heart block/PPM	3 (6)	4 (13)	.43[e]
Renal insufficiency/failure	3 (6)	2 (6)	>.99[e]
Pulmonary infection	6 (12)	3 (9)	>.99[e]
Endocarditis	1 (2)	0 (0)	>.99[e]
Tracheostomy	3 (6)	2 (6)	>.99[e]
Anaphylactic shock	1 (2)	0 (0)	>.99[e]
Atrial arrhythmia	14 (29)	2 (6)	.02[e]
Stroke	0 (0)	0 (0)	NA
Reintubation	3 (6)	2 (6)	>.99[e]
Cardiogenic stroke	1 (2)	1 (4)	>.99[e]
Delayed sternal closure	2 (4)	0 (0)	.52[e]
Reoperation during same admission	2 (4)	1 (3)	>.99[e]
LVEF < 50%	3 (6)	0 (0)	.27[e]
In-hospital death	1 (2)	0 (0)	NA

[a]Data were missing for 5 patients regarding duration of ventilator therapy and length of hospital stay.
[b]Surgery; no percutaneous intervention.
[c]Wilcoxon rank sum test.
[d]Diagnosed as acute heart failure.
[e]Fisher exact test.
LVEF, left ventricular ejection fraction; NA, not applicable; PPM, permanent pacemaker.

procedure. No patients required reoperation after percutaneous pulmonary valve replacement or reintervention (mean follow-up duration, 6 years).

The median hospital stay for surgical intervention was 6 days (range, 1-62 days). The mean duration of ventilator therapy was 1 day (range, 1-3 days). Two patients were reintubated, both of whom experienced early postoperative pulmonary infections (3 patients total). One of the patients with early pulmonary tract infection who was reintubated also required an intra-aortic balloon pump and tracheostomy. The most common postoperative complication was acute fluid retention requiring diuresis (acute heart failure), which occurred in 6 patients (18%). Left ventricular ejection fraction did not decrease postoperatively in any patient. Three patients who underwent valvular operation required pacemaker insertion during hospitalization (Table 5).

Patients in the new cohort had shorter hospital stays than those in the remote cohort (median [IQR], 6 [4-9] days vs 8 [7-11] days; P=.004) (Table 5). The new cohort had 1.4 fewer mean days of ventilator therapy than the remote cohort, but the difference was not significant. There was no significant difference in the number of postoperative complications between the remote and new cohorts (P=.44), and no significant correlation was found between the number of childhood operations and either hospital length of stay (r=−0.08, P=.68) or days receiving ventilator therapy (r=−0.13, P=.54). Rates of postoperative complications were low overall; 74% (60/81) had no complications (Supplemental Table 1, available online at http://www.mcpiqojournal.org). The most common

postoperative complication in the remote cohort was atrial arrhythmia (29%), which was less in the new cohort (6%, P=.01). The most common postoperative issue in the new cohort was fluid retention (19%), although no patients exhibited decreased left ventricular ejection fraction (Table 5). No significant differences were found in postoperative outcomes regardless of the number of previous cardiac procedures or the various preoperative diagnoses, except for kidney disease (Supplemental Table 2, available online at http://www.mcpiqojournal.org). Using data from the remote and new cohorts and a cutoff for serum creatinine of 1.5 mg/dL, we found an association between creatinine level and hospital length of stay (P=.009) and duration of ventilator therapy (P=.02). Patients with creatinine levels above 1.5 mg/dL were in the hospital longer and required ventilator therapy more than those with lower creatinine levels (Supplemental Table 2). Overall, the in-hospital postoperative mortality rate was low at 1.2% (0%, new cohort [0/32]; 2.0%, remote cohort [1/49]).

After hospital discharge, most patients did well. However, 2 patients were rehospitalized within 2 weeks: 1 for postpericardiotomy syndrome with moderate pericardial effusion requiring pericardiocentesis and the other for pleural effusion requiring thoracentesis. Another patient returned to the hospital in about a month because of a retained suture. Two patients were hospitalized 2 years postoperatively with acute endocarditis.

The mean follow-up period was 5 years (range, 3 days to 17 years); 3 patients did not complete follow-up care. Two late deaths occurred: a 44-year-old patient died of pneumonia 1 year postoperatively and the other 45-year-old patient died 10 years postoperatively of unknown causes. The patient who died of pneumonia had preoperative kidney failure requiring dialysis and postcapillary pulmonary hypertension. That patient also had several initial complications, including early pulmonary tract infection, reintubation, anemia, and heart failure, after his mitral valve replacement and tricuspid valve repair. The mean time between the date of the last cardiac operation and the date of death was 16 years. The most common causes of death were dementia for 6 patients, followed by pneumonia (3 patients), congestive heart failure (2 patients), and unknown cause (1 patient). The mean age at death was 51 years (both cohorts) (Supplemental Table 3, available online at http://www.mcpiqojournal.org).

DISCUSSION

Our study found changes in surgical patterns for patients with DS over the last 50 years. When we compared the remote cohort (1969-2007) with the new cohort (2009-2022), we found more childhood operations in the new cohort. This finding was consistent with patterns favoring cardiac operations in childhood, likely related to advances in diagnostic testing and palliative operation for critically ill newborns.[4] An increase in childhood operation was particularly noted for patients with TOF. All TOF-affected patients in the new cohort underwent complete TOF repair in childhood compared with none of the patients in the previous study. This finding was not surprising given that complete TOF repairs for children started in the 1980s.[13]

Despite a significant increase in prevalence of childhood operations performed, no significant difference existed in mean age at first adult intervention between the 2 cohorts. In another study of persons with various congenital heart anomalies, the reported mean age at cardiac operation (including initial operation and reoperations) was 49 and 40 years, respectively.[5] In this study, patients were younger—the mean age at adult intervention was 33 years.

Diagnosed preoperative comorbid conditions were similar between both cohorts and with reported study findings, with sleep apnea and thyroid abnormalities still being the most common.[1] Postoperative morbidity was low overall because nearly 75% of our population had no postoperative complications. The 26% complication rate is likely an overcautious estimate because volume overload (without a decrease in ejection fraction) was included as a complication. Often, patients experience some volume overload after their intensive care stay and respond to a small dose of a diuretic medication. Because edema was present without ventricular dysfunction, it was likely caused by increased use of fluids

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during the perioperative and postoperative periods. Therefore, we believe the complication rate was somewhat inflated; however, we felt it more important to overestimate than underestimate degree of risk. No significant difference existed in diagnosed postoperative complications between the 2 cohorts despite the noted increase in previous childhood operations in the new cohort.

The frequency of postoperative atrial arrhythmia decreased over time in our study, although atrial arrhythmia being the most common complication after cardiac operation reported in other studies. Reasons for the decrease are likely multifactorial, including earlier valvular interventions before sequelae, advancements in surgical technique, and temporary treatment with antiarrhythmic medications.[14,15] The decrease in "new" postoperative atrial arrhythmias in our study was perhaps related to the increased prevalence of preoperative, previously diagnosed atrial arrhythmia in the new cohort. Whether this increase in atrial arrhythmia is related to the increase in childhood operations—and thus a greater nidus for arrhythmia due to scarring—is unknown.

Preoperative hypercreatinemia (>1.5 mg/dL) was the only comorbid condition associated with longer hospital stay and duration of ventilator therapy. Elevated creatinine levels have been associated with a significant increase in morbidity and mortality after cardiac operation in the general population as well.[16]

Our study findings found significantly reduced hospital length of stay during the past few decades (median 8 days in the remote cohort; 6 days in the new cohort; P=.004), consistent with results from many published studies. Moreover, previous research findings have supported the safety of shorter hospital stays. In the 1990s, a change to fast-track protocols occurred, which enabled earlier extubation and mobilization of hospitalized patients and more discharges to nonacute care settings rather than home. Both factors resulted in decreased hospital stays after cardiac operation.[17,18]

Postoperative in-hospital mortality was low overall at 1.2% (1/81), with a 0% (0/32) mortality rate in the new cohort. The only patient from the remote cohort who died in the hospital postoperatively underwent an emergent operation because of a thrombosed mechanical mitral valve prosthesis and had multisystem organ failure. For all patients, the average time between the last cardiac operation and death was 16 years. The most common cause of death was dementia related, which occurred in 40% of the patients who died in our study. This finding contrasted with results from a registry that suggested the most common causes of death were respiratory tract infections and complications from congenital heart disease.[6]

An interesting update in this study was our data related to percutaneous valvular procedures, which have been approved and implemented within the past decade.[19,20] No patients in our study who underwent percutaneous valvular intervention had substantial periprocedural morbidity or mortality. This finding is not surprising because procedural success for transcatheter pulmonary valve intervention exceeds 96%, with more favorable outcomes for younger persons.[19,20] Our sample was small, and our patients were young (mean age, 23 years). In the remote cohort, percutaneous intervention was considered for a few older patients but not pursued because of patient dementia or because of low confidence that the procedure would succeed. In our study, the mean follow-up duration after percutaneous cardiac intervention was 6 years. Thus far, no patients have required a reintervention, and no death has occurred.

Study Limitations

Our study had several limitations. There were difficulties with data retrieval for some patients because our institution had changed from paper-based to electronic health records. In addition, some patients did not have follow-up at our institution, limiting the long-term outcome data. Sample sizes were also smaller than preferable. All patients underwent their adult cardiac procedures at our quaternary care center, which may contribute to referral bias and limit the generalizability of our results. Patients undergoing operation or percutaneous intervention were carefully selected for intervention after assessing risks and benefits; thus, our cohort may have been a lower-risk DS population.

CONCLUSION

Our study found that select adults with DS can undergo cardiac operation or percutaneous intervention at a quaternary care center with a low risk of morbidity and mortality and with good long-term survival. Future investigators may opt to reassess outcomes for greater numbers of patients undergoing percutaneous cardiac interventions because these procedures become more commonly offered.

POTENTIAL COMPETING INTERESTS

The authors report no competing interests.

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mcpiqojournal.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **AV,** atrioventricular; **DS,** Down syndrome; **TOF,** tetralogy of Fallot; **TPVR,** transcatheter pulmonary valve replacement

Data Availability Statement: All relevant, deidentified data supporting the findings of this study are reported within the article.

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