Bicuspid aortic valve interventions in Texas—2009–2019

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Background: Bicuspid aortic valve (BAV) is a common congenital heart defect occurring in 0.5–2% of adults. It is associated with increased lifetime risk of aortic valve intervention (AVI). Different AVI options include surgical replacement [surgical aortic valve replacement (SAVR)], repair, the Ross procedure, and transcatheter replacement [transcatheter aortic valve replacement (TAVR)]. This study seeks to evaluate statewide trends in BAV AVI and compare in-hospital outcomes over 11 years period.

Methods: A retrospective review of the Texas Inpatient Discharge Dataset from 1/1/2009–12/31/2019 was conducted. All non-trauma discharges of patients ≥18 years from acute care hospitals were included. BAV discharges, types of AVI, and outcomes were identified by International Classification of Diseases 9th and 10th revision (ICD-9/10) diagnosis codes. Descriptive, univariate, and logistic regression statistics were utilized.

Results: A total of 22,154,664 eligible discharges were identified, of which 10,393 (0.05%) were BAV discharges of which 5,429 (52.2%) underwent AVI, including included 126 (2.3%) repair, 204 (3.8%) TAVR, 5,015 (92.4%) SAVR and 84 (1.5%) Ross procedures. After adjusting for patient characteristics, SAVR had the longest length of stay (LOS) (P<0.001), the Ross procedure had an increased odds of acute renal failure (P=0.010) and TAVR an increased odds of permanent pacemaker placement (P=0.029) compared to repair. No difference was found in in-hospital mortality.

Conclusions: The number of BAV AVI discharges increased steadily over the study period. Different BAV AVI types are associated with different complication profile, including need for permanent pacemaker placement and acute renal failure. These differential risks should be utilized to inform patients and families to allow for more robust shared decision making within care plans for those with BAV.

Keywords: Aortic valve repair; aortic valve replacement; Ross operation; outcomes

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Introduction

The first description of bicuspid aortic valve (BAV) is attributed to Leonardo da Vinci who sketched the variant more than 400 years ago (1). BAV is a common congenital heart defect with a prevalence of 0.5–2% in adults (2). BAV can present within a wide spectrum, from newborn critical aortic stenosis, to asymptomatic which are incidentally identified to significant aortopathy, aneurysm and even

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dissection and rupture (3). Many BAV patients will require intervention for aortic valve stenosis, insufficiency, a combination of the two, and/or aortic dilation. In a cohort of adult BAV patients, 22% required aortic or aortic valve intervention (AVI) during a mean follow-up of 9 years (4).

Choice of intervention approach can be challenging and is influenced by myriad of things, including: underlying aortic valve morphology, patient age, patient wishes and surgical expertise. Aortic valve replacement with mechanical or biologic valve has been the standard for many years, with aortic valve repair and valve sparing procedures become more and more frequent (though still the minority) (5).

Replacement with a mechanical prosthesis, while more durable than biologic prostheses, results in rates of reoperation ranging from 0.5–1% per patient year and carries a mortality rate of approximately 1% per year (5-7). Mechanical replacements also require lifelong anticoagulation which impacts patient quality of life and presents an increased risk of hemorrhagic complications (8-11). Biologic protheses are faced with reduced durability (12). Other choices for intervention include the Ross procedure (13), aortic valve repair (5), and transcatheter aortic valve replacement (TAVR) (14).

Given the multitude of options for intervention, this study seeks to evaluate the trends in intervention types, patient characteristics, and outcomes from 2009 through 2019 in the state of Texas. We present the following article in accordance with the STROBE reporting checklist (available at https://asj.amegroups.com/article/view/10.21037/asj-22-17/rc).

Methods

Data source

Data was obtained from the Texas Inpatient Discharge Dataset (TIDD) from 2009–2019 (15). The TIDD is an administrative database that captures most discharges in the state of Texas with exception of hospitals located in a county with a population less than 35,000, or those located in a county with a population more than 35,000 and with fewer than 100 licensed hospital beds and not located in an area that is delineated as an urbanized area by the United States Bureau of the Census. These data are collected and maintained by the Texas Department of State Health Services, Center for Health Statistics. Data are deidentified when it is submitted to the dataset from the hospitals. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was reviewed by institutional review board of the University of Texas at Austin Dell Medical School (No. 2020-01-0052) and was deemed not human subjects research as the study consisted of existing, deidentified data thus individual consent for this analysis was waived.

Study population

The TIDD provides an admitting diagnosis, a principal diagnosis, up to 24 other diagnoses, a principal procedure and up to 24 other procedures for each hospitalization record. From 2009 through the third quarter of 2015, diagnoses and procedures were coded using the standard International Classification of Diseases, 9th edition (ICD-9). Records from the 4th quarter of 2015–2019 were coded using the 10th edition (ICD-10).

Inclusion criteria includes: discharges of patients ≥18 years of age at discharge and diagnosis of BAV, and AVI during the hospitalization. BAV discharges were identified as discharges with an ICD-9 code of 746.4 or ICD-10 code of Q23.1 listed. AVI were categorized into repair, Ross procedure, TAVR, and surgical aortic valve replacement (SAVR). AVI were identified by ICD-9 or ICD-10 procedure codes consistent with the intervention categories (Figure S1) .

We excluded from analysis: discharges from long term care, mental and behavior health facilities, substance abuse centers, and unknown center type, discharges of patients <18 years of age, trauma admissions, discharges with missing information on the type of admission, sex, age, race, ethnicity, length of stay (LOS), discharge status, admitting diagnosis, or principle diagnosis, and interim entries. Additionally, discharges with an ICD-9/10 diagnosis code consistent with thoracic or thoracoabdominal aortic dissection or rupture were excluded as the acute nature of these interventions were seen as a unique population which should not be compared with interventions outside of dissection or rupture.

Study outcomes

The primary aim of the study was to assess the trends in BAV interventions over the study period, evaluate patient characteristics between AVI and evaluate outcomes of the different AVI. The TIDD categorizes age into 16 groups. These were further collated into, 18–44, 45–64, and

Table 1 Demographic characteristics of bicuspid aortic valve with aortic valve intervention discharges

Variable	Bicuspid aortic valve with aortic valve intervention discharges, N=5,429 (%)
Female	1,479 (27.2)
Age (years)	
18–44	844 (15.5)
45–64	2,792 (51.4)
≥65	1,793 (33.0)
Race	
American Indian/Eskimo/Aleut	15 (0.3)
Asian or Pacific Islander	86 (1.6)
Black	134 (2.5)
White	4,434 (81.7)
Other	760 (14.0)
Hispanic	837 (15.4)
Insurance	
Uninsured	260 (4.8)
Private	4,211 (77.6)
Medicare/Medicaid	677 (12.5)
Unknown	3 (0.0)
Other	278 (5.1)

65+ years. Insurance status was grouped into private insurance, Medicare/Medicaid, uninsured, other, and unknown. Other patient characteristics were identified utilizing ICD-9/10 diagnosis codes listed in Figure S1.

Presence of additional congenital heart disease (CHD) diagnoses was identified as discharges of patients with an ICD-9/10 diagnosis of CHD listed which could be categorized by the American Heart Association/American College of Cardiology severity scale (Figure S1) (16). Discharges of patients with an isolated Atrial Septal Defect (ICD-9: 745.5, ICD-10: Q21.1) were not counted as CHD as isolated Atrial Septal Defect diagnosis codes have been shown to be erroneous more than 75% of the time in administrative datasets (17).

Outcomes included in-hospital mortality, LOS, requirements for a temporary pacemaker, permanent pacemaker, temporary mechanical circulatory support, extracorporeal membrane oxygenation (ECMO), invasive ventilatory support >96 hours, and acute renal failure. Other than mortality and LOS, outcomes were identified by ICD-9/10 diagnosis and procedure codes listed in Figure S1.

Statistical analysis

Descriptive statistics were reported for demographics, patient characteristics, and outcomes. LOS is reported in median (interquartile range) days. All other variables are presented as proportions. Chi-square and Fisher's exact tests were utilized to analyze discrete variables. The Kruskal Wallis test was utilized to analyze LOS. Multivariable linear and logistic regression analysis was performed to compare AVI type and outcomes. Statistical analyses were performed using R and RStudio (18). All statistical tests were 2-tailed and a P value <0.05 was considered significant.

Results

Overall AVIs in BAV

A total of 22,154,664 eligible discharges were identified. Of those, 10,393 (0.05%) were discharges of patients with BAV. Of the BAV discharges, 5,429 (52.2%) discharges underwent an AVI during the hospitalization. For the BAV with AVI discharges, 1,479 (27.2%) were female, 4,434 (81.7%) White, 837 (15.4%) Hispanic, 4,211 (77.6%) had private insurance and 677 (12.5%) had Medicare/Medicaid. The age distribution included 844 (15.5%) 18–44 years, 2,792 (51.4%) 45–64 years and 1,793 (33.0%) 65 years and older (*Table 1*). The AVI categories included 126 (2.3%) aortic valve repair, 204 (3.8%) TAVR, 5,015 (92.4%) SAVR and 84 (1.5%) Ross procedures (*Figure 1*). BAV AVI was performed at 142 centers with 97 (68.3%) only performing SAVR while 25 (17.6%) performed repairs, 30 (21.1%) performed TAVRs and 18 (12.7%) performed the Ross procedure. Seven (4.9%) centers performed all BAV AVI types during the study period. The median number of cases per center was 7 (IQR, 3–23).

Trends in BAV intervention

The number of BAV AVI discharges grew from 378 in 2009 to 677 in 2019, representing a 79% total increase and a 7.2% annual increase. The first TAVR discharges were in 2012 with 4 and increased to 85 in 2019, representing a 2,025% total increase and a 253% annual increase (*Figure 2*). SAVR represented 94.4% of BAV AVI in 2009, peaked at

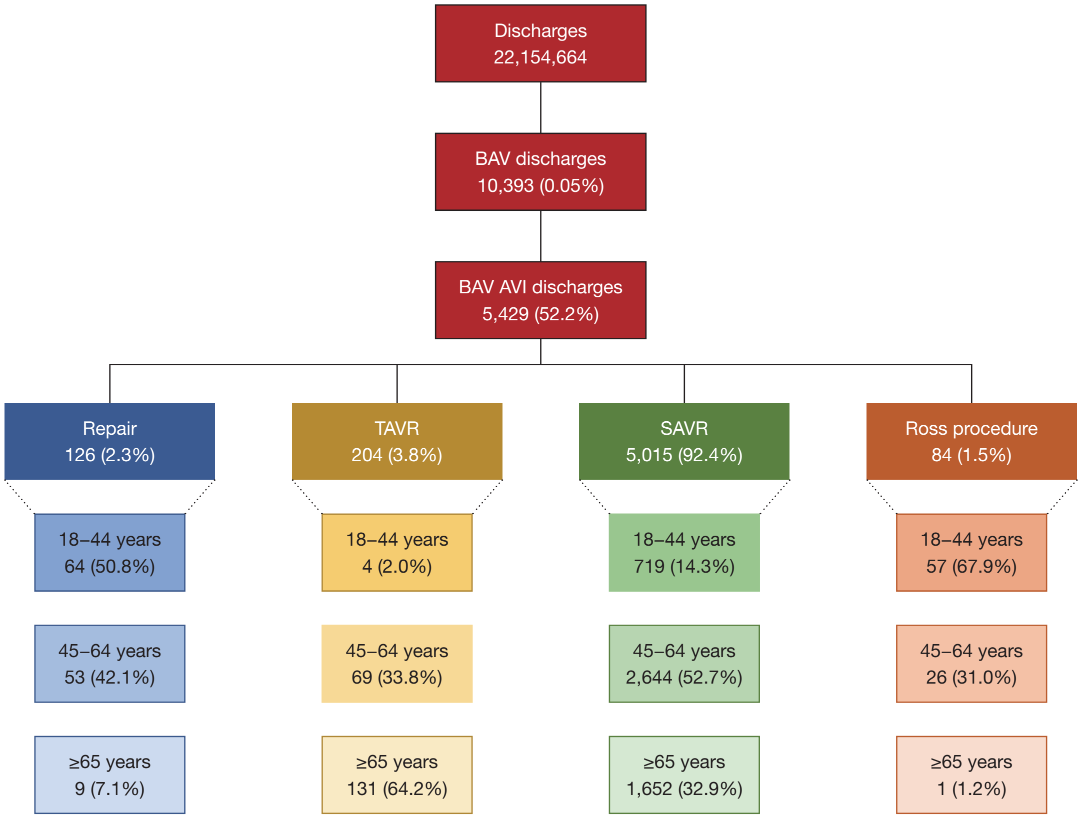


Figure 1 Aortic valve intervention types by age. BAV, bicuspid aortic valve; AVI, aortic valve intervention; TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.

97.9% in 2013 then declined to 83.0% in 2019. This was accompanied by an increase in proportion of TAVR from 0% in 2009 to 1.3% in 2015 and 12.6% in 2019. The proportion of Ross procedures and aortic valve repairs remained stable representing 1–4% of all interventions individually (*Figure 2*).

Discharge demographics by AVI type

Comparing different AVI modalities, TAVR discharges were more likely to be female (39.2%, P<0.001), repair and Ross procedure were younger (P<0.001), and TAVR discharges were least likely to have private insurance (58.8%) and most likely to have Medicare/Medicaid (32.4%, P<0.001). No differences were found in racial or ethnic makeups (*Table 2*).

Clinical characteristic by AVI type

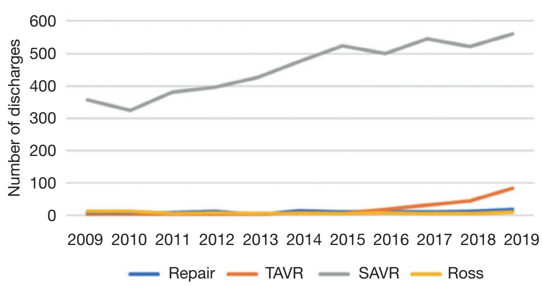
Ross procedure discharges were most likely to have a concomitant CHD diagnosis (19.0%, P<0.001). Aortic valve repair discharges were more likely to have a concomitant diagnosis of thoracic aortic dilation (73.4%, P<0.001) and a diagnosis of Turner Syndrome (2.4%, P=0.009). TAVR had the highest proportion of concomitant hypertension (87.3%, P<0.001), lipid disorders (68.6%, P<0.001), and Diabetes (28.9%, P=0.011). SAVR had the highest rate of smoking (19.2%, P<0.001) (*Table 3*).

Outcomes by AVI type

Overall the median LOS was 7 [5–9] days. There were 88(1.6%) in-hospital mortalities. There was a significant difference in LOS between the intervention types with SAVR having the longest at 7 [5–9] days and TAVR having the shortest at 2 [1–5] days (P<0.001). In-hospital mortality ranged from 1 (0.8%) in the repair group to 5 (2.5%) in the TAVR group; however, this did not reach statistical significance (P=0.517). TAVR had the highest incidence of permanent pacing (8.8%, P=0.006) and temporary pacing (17.2%, P<0.001) (*Table 4*).

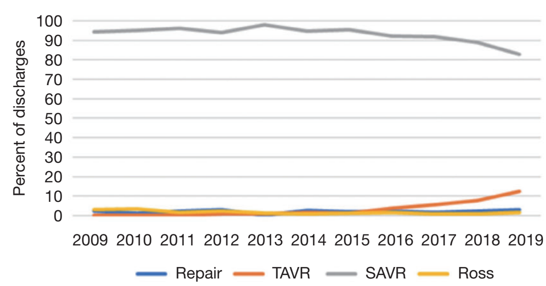
Overall

A Number of aortic valve interventions by type



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	9	4	9	12	1	14	11	13	10	13	20
TAVR				4	3	8	7	20	32	45	85
SAVR	357	325	381	396	426	476	524	501	545	522	562
Ross	12	12	6	9	5	5	6	8	5	6	10

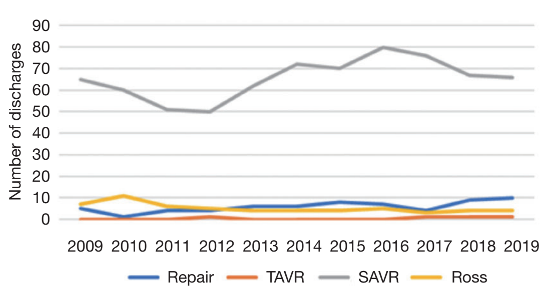
B Percentage of aortic valve interventions by type



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	2.4	1.2	2.3	2.9	0.2	2.8	2.0	2.4	1.7	2.2	3.0
TAVR				1.0	0.7	1.6	1.3	3.7	5.4	7.7	12.6
SAVR	94.4	95.3	96.2	94.1	97.9	94.6	95.6	92.4	92.1	89.1	83.0
Ross	3.2	3.5	1.5	2.1	1.1	1.0	1.1	1.5	0.8	1.0	1.5

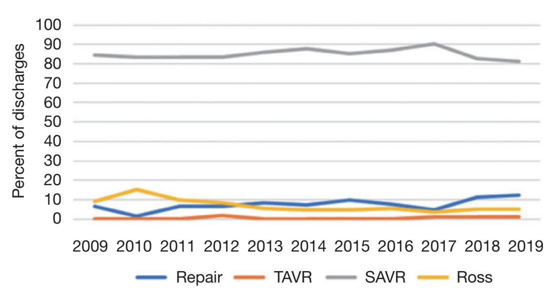
18–44 years

C Number of aortic valve interventions by type



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	5	1	4	4	6	6	8	7	4	9	10
TAVR				1					1	1	1
SAVR	65	60	51	50	62	72	70	80	76	67	66
Ross	7	11	6	5	4	4	4	5	3	4	4

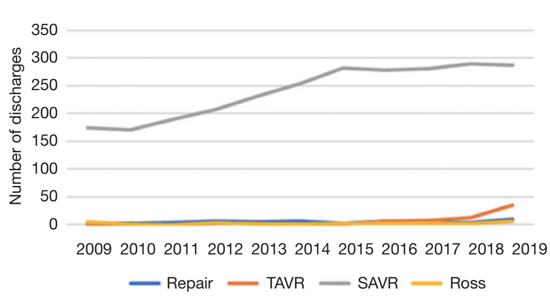
D Percentage of aortic valve interventions by type



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	6.5	1.4	6.6	6.7	8.3	7.3	9.8	7.6	4.8	11.1	12.3
TAVR				1.7					1.2	1.2	1.2
SAVR	84.4	83.3	83.6	83.3	86.1	87.8	85.4	87.0	90.5	82.7	81.5
Ross	9.1	15.3	9.8	8.3	5.6	4.9	4.9	5.4	3.6	4.9	4.9

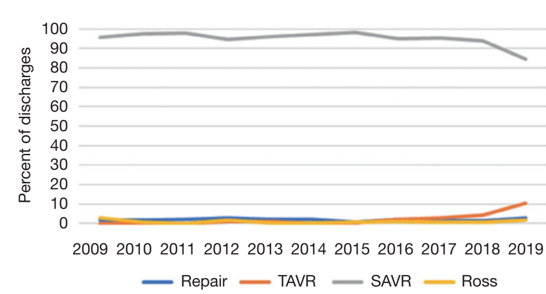
45–64 years

E Number of aortic valve interventions by type



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	3	3	4	6	5	6	2	6	4	4	10
TAVR				2	3		1	6	8	13	36
SAVR	174	171	190	207	231	254	282	278	281	289	287
Ross	5	1		4	1	1	2	3	2	2	6

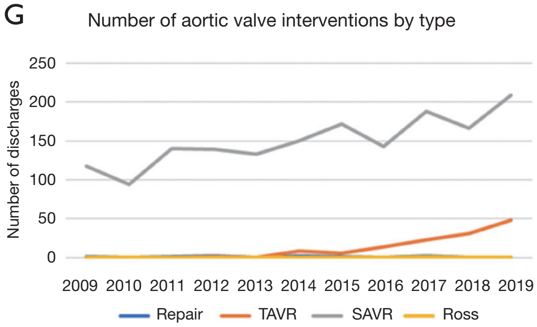
F Percentage of aortic valve interventions by type



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	1.6	1.7	2.1	2.7	2.1	2.3	0.7	2.0	1.4	1.3	2.9
TAVR				0.9	1.3		0.3	2.0	2.7	4.2	10.6
SAVR	95.6	97.7	97.9	94.5	96.3	97.3	98.3	94.9	95.3	93.8	84.7
Ross	2.7	0.6		1.8	0.4	0.4	0.7	1.0	0.7	0.6	1.8

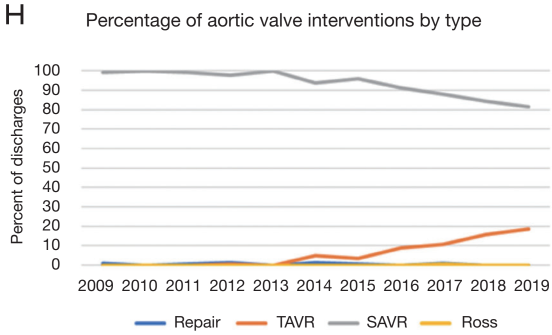
65+ years

G



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	1		1	2		2	1		2		
TAVR				1		8	6	14	23	31	48
SAVR	118	94	140	139	133	150	172	143	188	166	209
Ross									1		

H



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Repair	0.8		0.7	1.4		1.3	0.6		0.9		
TAVR				0.7		5.0	3.4	8.9	10.7	15.7	18.7
SAVR	99.2	100.0	99.3	97.9	100.0	93.8	96.1	91.1	87.9	84.3	81.3
Ross									0.5		

Figure 2 Number and percentage of aortic valve intervention types over time, overall and by ages. (A,B) Overall population; (C,D) 18–44 years of age; (E,F) 45–64 years of age; (G,H) 65 years of age and older. TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.

Table 2 Demographics of discharges by aortic valve intervention type

Variable	Repair (N=126)	TAVR (N=204)	SAVR (N=5,015)	Ross (N=84)	Significance
Female	29 (23.0)	80 (39.2)	1,345 (26.8)	25 (29.8)	<0.001
Age (years)					
18–44	64 (50.8)	4 (2.0)	719 (14.3)	57 (67.9)	<0.001
45–64	53 (42.1)	69 (33.8)	2,644 (52.7)	26 (31.0)	
≥65	9 (7.1)	131 (64.2)	1,652 (32.9)	1 (1.2)	
Race					
American Indian/Eskimo/Aleut	1 (0.8)	0	13 (0.3)	1 (1.2)	0.072
Asian or Pacific Islander	4 (3.2)	4 (2.0)	75 (1.5)	3 (3.6)	
Black	1 (0.8)	6 (2.9)	126 (2.5)	1 (1.2)	
White	94 (74.6)	172 (84.3)	4,102 (81.8)	66 (78.6)	
Other	26 (20.6)	22 (10.8)	699 (13.9)	13 (15.5)	
Hispanic	18 (14.3)	45 (22.1)	762 (15.2)	12 (14.3)	0.063
Insurance					
Uninsured	8 (6.5)	10 (4.9)	238 (4.8)	4 (4.8)	<0.001
Private	95 (76.6)	120 (58.8)	3,927 (78.3)	69 (82.1)	
Medicare/Medicaid	9 (7.3)	66 (32.4)	596 (11.9)	6 (7.1)	
Unknown	1 (0.8)	0	2 (0.0)	0	
Other	13 (10.5)	8 (3.9)	252 (5.0)	5 (6.0)	

TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.

Table 3 Clinical characteristics of discharges by aortic valve intervention type

Variable	Repair (N=126)	TAVR (N=204)	SAVR (N=5,015)	Ross (N=84)	Significance
Aortic dilation	91 (73.4)	33 (26.6)	1,736 (34.6)	20 (23.8)	<0.001
Congenital heart disease	8 (6.3)	3 (1.5)	253 (5.0)	16 (19.0)	<0.001
Turner syndrome	3 (2.4)	1 (0.5)	12 (0.2)	0	0.009
Marfan syndrome	1 (0.8)	0	17 (0.3)	0	0.585
Ehlers-Danlos syndrome	0	0	3 (0.1)	0	1
Hypertension	84 (66.7)	178 (87.3)	3,643 (72.6)	45 (53.6)	<0.001
Atherosclerosis (non-coronary)	1 (0.8)	13 (6.4)	149 (3.0)	1 (1.2)	0.231
Lipid disorder	40 (31.7)	140 (68.6)	2,700 (53.8)	24 (28.6)	<0.001
Diabetes	16 (12.7)	59 (28.9)	997 (19.9)	1 (1.2)	0.011
Smoking	23 (18.3)	16 (7.8)	965 (19.2)	11 (13.1)	<0.001
Coronary artery bypass	9 (7.1)	1 (0.5)	842 (16.8)	4 (4.8)	<0.001

The data are expressed as n (%). TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.

Table 4 Clinical outcomes of discharges by aortic valve intervention type

Variable	Repair (N=126)	TAVR (N=204)	SAVR (N=5,015)	Ross (N=84)	Significance
Length of stay (days)	5 [4–7]	2 [1–5]	7 [5–9]	5 [4–6]	<0.001
In-hospital mortality	1 (0.8)	5 (2.5)	80 (1.6)	2 (2.4)	0.517
Extracorporeal membrane oxygenation	1 (0.8)	3 (1.5)	34 (0.7)	1 (1.2)	0.284
Temporary mechanical circulatory support	0	0	7 (0.1)	1 (1.2)	0.191
Permanent ventricular assist device	2 (1.6)	0	5 (0.1)	1 (1.2)	0.004
Temporary pacing	9 (7.1)	35 (17.2)	270 (5.4)	2 (2.4)	<0.001
Permanent pacemaker	1 (0.8)	18 (8.8)	270 (5.4)	2 (2.4)	0.006
Acute renal failure	12 (9.5)	24 (11.8)	721 (14.4)	16 (19.0)	0.173
Ventilator support >96 hours	2 (1.6)	3 (1.5)	133 (2.7)	1 (1.2)	0.731

The data are expressed as n (%) or median [IQR]. TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.

AVI in young adults (18–44 years)

A total of 844 AVI discharges occurred in patients 18–44 years of age, accounting for 15.5% of all BAV AVI discharges. In this group, 719 (85.2%) underwent SAVR, 64 (7.6%) underwent repair, 57 (6.8%) underwent a Ross procedure and 4 (0.5%) underwent TAVR. Given the small number of TAVR interventions, these were not included in the following analysis. No demographic differences were seen between the three intervention groups. Ross procedures were more likely to have a concomitant CHD diagnosis (26.3%, P=0.004). The repair group was more likely to have aortic dilation (57.8%, P<0.001). SAVR had the longest LOS at 7 [5–10] days (P<0.001). There were 12 (1.4%) in-hospital mortalities with 11 (1.5%) in the SAVR group, 1 (1.8%) in the Ross procedure group and 0 in the repair group. This did not reach statistical significance (P=0.682). SAVR was more likely to require permanent pacemaker placement (6.4%, P=0.030) (*Table 5*).

Multivariable model of outcomes

After adjusting for demographic and clinical characteristics, type of AVI continued to have no association with mortality, requirement for ventilatory support >96 hours and temporary

Table 5 Demographics, clinical characteristics and outcomes of discharges by aortic valve intervention type for patients 18 to 44 years

Variable, n (%)	Repair (N=64)	SAVR (N=719)	Ross (N=57)	Significance
Female	16 (25.0)	148 (20.6)	14 (24.6)	0.576
Race				
American Indian/Eskimo/Aleut	1 (1.6)	2 (0.3)	1 (1.8)	0.287
Asian or Pacific Islander	1 (1.6)	10 (1.4)	2 (3.5)	
Black	1 (1.6)	26 (3.6)	1 (1.8)	
White	47 (73.4)	554 (77.1)	44 (77.2)	
Other	14 (21.9)	127 (17.7)	9 (15.8)	
Hispanic	14 (21.9)	160 (22.3)	8 (14.0)	0.349
Insurance				
Uninsured	4 (6.3)	77 (10.7)	4 (7.0)	0.267
Private	46 (71.9)	533 (76.9)	45 (78.9)	
Medicare/Medicaid	5 (7.8)	66 (9.2)	6 (10.5)	
Unknown	0	0	0	
Other	9 (14.1)	43 (6.0)	2 (3.5)	
Aortic dilation	37 (57.8)	286 (39.8)	13 (22.8)	<0.001
Congenital heart disease	7 (10.9)	82 (11.4)	15 (26.3)	0.004
Turner syndrome	3 (4.7)	8 (1.1)	0	0.095
Marfan syndrome	1 (1.6)	14 (1.9)	0	0.854
Ehlers-Danlos syndrome	0	2 (0.3)	0	1
Hypertension	35 (54.7)	358 (49.8)	28 (49.1)	0.745
Atherosclerosis (non-coronary)	1 (1.6)	9 (1.3)	0	0.791
Lipid disorder	15 (23.4)	151 (21.0)	10 (17.5)	0.726
Diabetes	4 (6.3)	49 (6.8)	1 (1.8)	0.366
Smoking	10 (15.6)	126 (17.5)	7 (12.3)	0.571
Coronary artery bypass	1 (1.6)	23 (3.2)	2 (3.5)	0.751
Length of stay (days)	5 [4–7]	7 [5–10]	5 [4–6]	<0.001
In-hospital mortality	0	11 (1.5)	1 (1.8)	0.682
Extracorporeal membrane oxygenation	0	8 (1.1)	0	1
Temporary mechanical circulatory support	0	2 (0.3)	0	1
Permanent ventricular assist device	0	1 (0.1)	0	1
Temporary pacing	4 (6.3)	31 (4.3)	0	0.187
Permanent pacemaker	0	46 (6.4)	1 (1.8)	0.030
Ventilatory support >96 hours	0	22 (3.1)	1 (1.8)	0.475
Acute renal failure	4 (6.3)	87 (12.1)	11 (19.3)	0.090

The data are expressed as n (%) or median [IQR]. TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.

Table 6 Multivariable models

Variable	Length of stay			Acute renal failure			Permanent pacing		
	Percent change	95% CI	Sig.	OR	95% CI	Sig.	OR	95% CI	Sig.
AVI type									
Repair	Ref.			Ref.			Ref.		
TAVR	−53.2%	−58.5%, −47.2%	<0.001	1.0	0.5–2.3	0.930	9.8	1.9–179.1	0.029
SAVR	24.6%	12.4%, 35.8%	<0.001	1.5	0.9–3.0	0.186	7.1	1.6–125.2	0.052
Ross	−6.0%	−18.7%, 8.7%	0.402	3.0	1.3–7.0	0.010	2.7	0.3–58.6	0.424
White	−7.4%	−10.6%, −4.0%	<0.001	0.8	0.7–1.0	0.063	0.9	0.7–1.2	0.414
Female	−0.2%	−3.3%, 3.1%	0.918	0.6	0.5–0.7	<0.001	1.4	1.1–1.8	0.011
Age (years)									
18–44	Ref.			Ref.			Ref.		
45–64	−1.5%	−5.8%, 2.9%	0.484	1.0	0.8–1.3	0.828	0.9	0.6–1.3	0.500
≥65	1.5%	−3.4%, 6.6%	0.556	1.4	1.1–1.9	0.012	1.0	0.7–1.6	0.894
Intervention year	−1.2%	−1.6%, −0.7%	<0.001	1.0	1.0–1.1	0.010	1.0	1.0–1.0	0.900
Insurance									
Uninsured	Ref.			Ref.			Ref.		
Private	−32.6%	−37.0%, −28.0%	<0.001	0.6	0.4–0.9	0.005	0.5	0.3–0.8	0.002
Medicare/Medicaid	−17.9%	−24.0%, −11.3%	<0.001	1.0	0.7–1.4	0.843	0.7	0.4–1.2	0.175
Unknown	−23.7%	−58.1%, 39.1%	0.378	10.2	0.9–237.3	0.072	0.0	0–>2,000	0.973
Other	−27.0%	−33.2%, −20.2%	<0.001	1.1	0.7–1.7	0.699	0.3	0.1–0.7	0.006
Congenital heart disease	2.7%	−3.7%, 9.5%	0.413	0.9	0.6–1.3	0.752	1.5	0.9–2.4	0.087
Coronary artery bypass	19.1%	14.5%, 23.9%	<0.001	1.9	1.5–2.3	<0.001	0.8	0.6–1.2	0.319
Hypertension	−0.4%	−3.7%, 3.0%	0.802	1.2	1.0–1.4	0.142	0.8	0.6–1.0	0.050
Diabetes	8.8%	4.9%, 12.8%	<0.001	1.2	1.0–1.5	0.052	1.3	0.9–1.7	0.132
Lipid disorder	−9.0%	−11.7%, −6.1%	<0.001	0.9	0.7–1.1	0.179	1.0	0.8–1.3	0.812
Atherosclerosis (non-coronary)	5.8%	−2.6%, 14.8%	0.181	1.3	0.8–1.9	0.270	1.6	0.9–2.8	0.094
Smoking	−2.5%	−6.1%, 1.2%	0.177	0.8	0.6–1.0	0.046	0.7	0.5–1.0	0.094

AVI, aortic valve intervention; TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement; Sig., significance.

pacing. Compared to repair, TAVR had a 53.2% (95% CI: 47.2–58.5%, P<0.001) reduced LOS while SAVR had a 24.6% (95% CI: 12.4–35.8%, P<0.001) increased LOS. Further, the Ross procedure had an increased adjusted odds of acute renal failure (adjusted OR: 2.80, 95% CI: 1.23–6.54, P=0.015) and TAVR had an increased adjusted odds of permanent pacemaker placement (adjusted OR: 10.1, 95% CI: 1.99–183.5, P=0.027) compared to repair (*Table 6*).

Discussion

In this review of a statewide administrative dataset over 11 years, 0.05% of the discharges were of patients with BAV, this correlates favorably with the overall reported prevalence of BAV in 1% of the general population. There was a steady increase in the number of AVI in BAV discharges of adult patients. Approximately half of all discharges with a diagnosis of BAV involved an AVI. SAVR accounted for the vast majority of these interventions across all ages. The first TAVR intervention in a BAV discharge in this dataset occurred in 2012 with fewer than 10 performed annually until 2016 with rapid increase in utilization thereafter. In 2019, TAVR accounted for 12.6% of all AVI in BAV discharges and 18.7% of AVI in the ≥65 years age group. The Ross procedure and aortic valve repair were almost exclusively performed in younger patients with >90% performed in those <65 years and >50% performed in those 18–44 years old.

TAVR had a significantly shorter LOS after adjusting for patient characteristics, representing the less invasive nature of the intervention. Contrarily, SAVR had a significantly longer LOS after adjusting for patient characteristics. As the invasiveness, on average, of SAVR would not be expected to be greater than repair or the Ross procedure, this increased LOS may represent patient complexity not captured and accounted for in this dataset. However, an intrinsic difference in recovery rates as a result of having a native tissue valve compared to a bioprosthetic or mechanical valve cannot be excluded.

A total of 88 (1.6%) in-hospital mortalities were identified, with 2.5% in TAVR, 2.4% in Ross procedures, 1.6% in SAVR and 0.8% in AV Repairs. However, no statistical differences in mortality rates was found between AVI type in unadjusted analysis and when adjusted for patient characteristics. This in-hospital mortality rate is favorable compared to previous report of 2.7% in analysis of real world data comparing TAVR to SAVR (19).

After adjustment for patient characteristics, the Ross procedure was associated with an increased odd of acute renal failure with a prevalence of 19% of BAV Ross procedure discharges. This increased risk is consistent with previous reports of increased acute renal failure post Ross procedure compared to Mechanical SAVR (6). Acute renal failure after cardiac surgery is a well described risk for late mortality (20). Given the increased complexity of the Ross, the resultant increased operative and cardiopulmonary bypass time may contribute to this increased risk.

An increased risk of permanent pacemaker placement was found in the TAVR intervention with a rate of 9% of BAV TAVR discharges. Increased rates of permanent pacing requirements have previously been reported however at a an even higher rate than identified in this study (21). The current analysis likely under-reports the true rates of permanent pacing as many pacemaker implantations may occur after the initial discharge from TAVR or not properly captured in this administrative dataset. It should be noted that these data represent many years of early utilization of TAVR in the BAV population. Early uses of TAVR likely involved higher risk patients which potentially impacts frequency of outcomes. As indications for TAVR continue to expand and volumes and experience with the procedure increase real-world outcomes will continue to need to be reassessed.

In an important sub-group analysis of the youngest (18–44 years) age group, SAVR was found to have the longest LOS, similar to the overall group. There were 11 (1.5%) in-hospital mortalities in the SAVR group, 1 (1.8%) in the Ross group and 0 in the repair group. This represents a low but not insignificant risk of in-hospital mortality in younger adults with BAV undergoing AVI. With intervention occurring at a young age, complications which result in chronic conditions take on a greater importance. In this young adult group, SAVR was associated with a high incidence of need for permanent pacing at 6.4% and significantly higher than Ross procedure (1.8%) and repair (0%). Requirement for permanent pacing in young adults has a significant impact on survival with only 70% survival at 20 years after initial implantation in a cohort of young adults (22).

Limitations

This is a retrospective analysis of an administrative dataset with the usual limitations including the lack of complete clinical data for individual patients. There is no information known about each individual's surgical history, particularly previous cardiac interventions and valve morphology and thus attributed interventional risk. Further, as the unit of analysis is a hospital discharge without any unique patient identifiers, there is a possibility that a single patient may be represented multiple times if they underwent repeated interventions during the study period.

While the ICD-9/10 code of Congenital Aortic Valve Insufficiency is the standard code utilized for BAV, it may also capture patients who do indeed have congenital aortic valve insufficiency in the setting of a tricuspid aortic valve. Further, there is the potential that BAV discharges were not identified if they were coded as Congenital Aortic Valve Stenosis.

Given the nature of the dataset, indication for intervention and if patients were offered and/or were eligible for different intervention types cannot be assessed. This potentially presents a bias towards all patients evaluated not being eligible for all procedures evaluated. However, the multivariable analysis of outcomes attempts to account for potential patient specific differences between the procedure types.

The lack of temporality in diagnostic codes inhibited the ability to assess important outcomes including myocardial infarction and neurological complications. In this dataset, presence of a diagnosis code consistent with either of these conditions may represent a historical event or an acute event thus these were not assessed in this analysis but represent important outcomes to be evaluated in future research.

Conclusions

Choice of AVI in patients with BAV requires evaluation of many factors. As the number of interventions continues to increase year over year, and with the introduction of new technologies, it is imperative to continue developing an understanding of the short- and long-term complications and outcomes of each intervention. The data in this study reveal significant differences in short-term outcomes which have the potential to impact long-term survival and quality of life. This information must then be used to further shared decision making with patients and families to determine the best path forward for each individual patient. Continued research on short- and long-term outcomes is necessary as experience grows with interventions such as TAVR and as new devices and interventions are introduced to ensure patients are provided with the most updated and accurate information when discussing treatment pathways.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://asj.amegroups.com/article/view/10.21037/asj-22-17/rc

Data Sharing Statement: Available at https://asj.amegroups.com/article/view/10.21037/asj-22-17/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://asj.amegroups.com/article/view/10.21037/asj-22-17/coif). The authors have no conflicts of interest to declare

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was reviewed by institutional review board of the University of Texas at Austin Dell Medical School (No. 2020-01-0052) and was deemed not human subjects research as the study consisted of existing, deidentified data thus individual consent for this analysis was waived.

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Supplementary

Congenital aortic insufficiency (bicuspid aortic valve)		Thoracic and thoracoabdominal aortic dissections and ruptures	
746.4, Q23.1		441.01, 441.03, I71.01, I71.03, 441.1, 441.10, 441.6, 441.60, I71.1, I71.5	
Aortic valve interventions			
Repair	Transcatheter aortic valve replacement	Surgical aortic valve replacement	Ross procedure
Only 02QF0ZZ, 35.11, 027F0ZZ, 02NF0ZZ	02RF38Z, 02RF3JZ, 02RF3KZ, 02RF37Z, 02RF38Z, 02RF3JZ, 02RF3KZ, 35.05	02RF07Z, 02RF08Z, 02RF0JZ, 02RF0KZ, 35.21, 35.22	02RF07Z, 35.21 + Pulmonary Valve Intervention or Right Ventricle to Pulmonary Artery Conduit
Congenital heart disease			
Diagnosis	ICD9/10 Code	Diagnosis	ICD9/10 Code
Ventricular septal defect	745.4, Q21.0	Ebstein's anomaly	746.2, Q22.5
Pulmonary infundibular stenosis	Q24.3	Supravalvar aortic stenosis	756.81, Q25.3
Coarctation of the aorta	747.10, Q25.1	Partial anomalous pulmonary venous return	747.42, Q26.3
Atrial ventricular septal defect	745.69, Q21.2	Tetralogy of Fallot	745.2, Q21.3
Congenital pulmonary valve stenosis	746.02. Q22.1	Congenital pulmonary valve insufficiency	Q22.2
Congenital stenosis of aortic valve	746.3, Q23.0	Congenital mitral valve stenosis	Q23.2
Other/unspecified congenital malformation of aortic or mitral valve	Q23.8, Q23.9	Congenital subaortic stenosis	Q24.4
Coarctation of the pulmonary artery	Q25.71	Endocardial cushion defect	745.69
Total anomalous pulmonary venous return	747.41, Q26.2	Truncus arteriosus	745.0, Q20.0
Double outlet right ventricle	745.11, Q20.1	D-transposition of the great arteries	745.10, Q20.3
Other single ventricle	745.3, 746.1, Q20.4, Q22.6	Discordant atrial-ventricular connection	Q20.5
Atrial isomerism	Q20.6	Interruption of the Aortic arch	747.11, Q25.21
Congenitally corrected transposition of the great arteries	745.12	Hypoplastic left heart syndrome	746.7, Q23.5
Pulmonary artery atresia	Q25.5		
Risk factors			
Turner syndrome	758.6, Q96.9	Marfan syndrome	759.82, Q87.40, Q87.410, Q87.418, Q87.42, Q87.43
Elhers-Danlos syndrome	756.83, Q79.6		
Hypertension		Atherosclerosis (non-coronary)	
401.0, 401.1, 401.9, 402.00, 402.01, 402.10, 402.11, 402.90, 402.91, 403.00, 403.01, 403.10, 403.11, 403.90, 403.91, 404.00, 404.01, 404.02, 404.03, 404.10, 404.11, 404.12, 404.13, 404.90, 404.91, 404.92, 404.93, 405.01, 405.09, 405.11, 405.19, 405.91, 405.99, 642, I10, I11.0, I11.9, I12.0, I12.9, I13.0, I13.10, I13.11, I13.2, I15.0, I15.1, I15.2, I15.8, I15.9, I16.0, I16.1, I16.9, O10.011, O10.012, O10.013, O10.019, O10.02, O10.03, O10.111, O10.112, O10.113, O10.119, O10.12, O10.13, O10.211, O10.212, O10.213, O10.219, O10.22, O10.23, O10.311, O10.312, O10.313, O10.319, O10.32, O10.33, O10.411, O10.412, O10.413, O10.419, O10.42, O10.43, O109.11, O10.912, O10.913, O10.919, O10.92, O10.93, O11.1, O11.2, O11.3, O11.4, O11.5, O11.9, O13.1, O13.2, O13.3, O13.4, O13.5, O13.9, O16.1, O16.2, O16.3, O16.4, O16.5, O16.9		440.0, 440.1, 440.4, 440.8, 440.9, 440.20, 440.21, 440.22, 440.23, 440.24, 440.29, 440.30, 440.31, 440.32, I70.0, I70.1, I70.201, I70.202, I70.203, I70.208, I70.209, I70.211, I70.212, I70.213, I70.218, I70.219, I70.221, I70.222, I70.223, I70.228, I70.229, I70.231, I70.232, I70.233, I70.234, I70.235, I70.238, I70.239, I70.241, I70.242, I70.243, I70.244, I70.245, I70.248, I70.249, I70.25, I70.261, I70.262, I70.263, I70.268, I70.269, I70.291, I70.292, I70.293, I70.298, I70.299, I70.301, I70.302, I70.303, I70.308, I70.309, I70.311, I70.312, I70.313, I70.318, I70.319, I70.321, I70.322, I70.323, I70.328, I70.329, I70.331, I70.332, I70.333, I70.334, I70.335, I70.338, I70.339, I70.341, I70.342, I70.343, I70.344, I70.345, I70.348, I70.349, I70.35, I70.361, I70.362, I70.363, I70.368, I70.369, I70.391, I70.392, I70.393, I70.398, I70.399, I70.401, I70.402, I70.403, I70.408, I70.409, I70.411, I70.412, I70.413, I70.418, I70.419, I70.421, I70.422, I70.423, I70.428, I70.429, I70.431, I70.432, I70.433, I70.434, I70.435, I70.438, I70.439, I70.441, I70.442, I70.443, I70.444, I70.445, I70.448, I70.449, I70.45, I70.461, I70.462, I70.463, I70.468, I70.469, I70.491, I70.492, I70.493, I70.498, I70.499, I70.501, I70.502, I70.503, I70.508, I70.509, I70.511, I70.512, I70.513, I70.518, I70.519, I70.521, I70.522, I70.523, I70.528, I70.529, I70.531, I70.532, I70.533, I70.534, I70.535, I70.538, I70.539, I70.541, I70.542, I70.543, I70.544, I70.545, I70.548, I70.549, I70.55, I70.561, I70.562, I70.563, I70.568, I70.569, I70.591, I70.592, I70.593, I70.598, I70.599, I70.601, I70.602, I70.603, I70.608, I70.609, I70.611, I70.612, I70.613, I70.618, I70.619, I70.621, I70.622, I70.623, I70.628, I70.629, I70.631, I70.632, I70.633, I70.634, I70.635, I70.638, I70.639, I70.641, I70.642, I70.643, I70.644, I70.645, I70.648, I70.649, I70.65, I70.661, I70.662, I70.663, I70.668, I70.669, I70.691, I70.692, I70.693, I70.698, I70.699, I70.701, I70.702, I70.703, I70.708, I70.709, I70.711, I70.712, I70.713, I70.718, I70.719, I70.721, I70.722, I70.723, I70.728, I70.729, I70.731, I70.732, I70.733, I70.734, I70.735, I70.738, I70.739, I70.741, I70.742, I70.743, I70.744, I70.745, I70.748, I70.749, I70.75, I70.761, I70.762, I70.763, I70.768, I70.769, I70.791, I70.792, I70.793, I70.798, I70.799, I70.8, I70.90, I7091	
Lipid disorder		Diabetes	

272.0, 272.1, 272.2, 272.3, 272.4, 272.5, 272.6, 272.7, 272.8, 272.9, E78.4, E78.00, E78.01, E78.2, E78.49, E78.5	250.00, 250.01, 250.02, 250.03, 250.10, 250.11, 250.12, 250.13, 250.20, 250.21, 250.22, 250.23, 250.30, 250.31, 250.32, 250.33, 250.40, 250.41, 250.42, 250.43, 250.50, 250.51, 250.52, 250.53, 250.60, 250.61, 250.62, 250.63, 250.70, 250.71, 250.72, 250.73, 250.80, 250.81, 250.82, 250.83, 250.90, 250.91, 250.92, 250.93, O24.011, O24.012, O24.013, O24.019, O24.02, O24.03, O24.111, O24.112, O24.113, O24.119, O24.12, O24.13, O24.311, O24.312, O24.313, O24.319, O24.32, O24.33, O24.811, O24.812, O24.813, O24.819, O24.82, O24.83, O24.911, O24.912, O24.913, O24.919, O24.92, O24.93, E08.00, E08.01, E08.10, E08.11, E08.21, E08.22, E08.29, E08.311, E08.319, E08.3211, E08.3212, E08.3213, E08.3219, E08.3291, E08.3292, E08.3293, E08.3299, E08.3311, E08.3312, E08.3313, E08.3319, E08.3391, E08.3392, E08.3393, E08.3399, E08.3411, E08.3412, E08.3413, E08.3419, E08.3491, E08.3492, E08.3493, E08.3499, E08.3511, E08.3512, E08.3513, E08.3519, E08.3521, E08.3522, E08.3523, E08.3529, E08.3531, E08.3532, E08.3533, E08.3539, E08.3541, E08.3542, E08.3543, E08.3549, E08.3551, E08.3552, E08.3553, E08.3559, E08.3591, E08.3592, E08.3593, E08.3599, E08.36, E08.37X1, E08.37X2, E08.37X3, E08.37X9, E08.39, E08.40, E08.41, E08.42, E08.43, E08.44, E08.49, E08.51, E08.52, E08.59, E08.610, E08.618, E08.620, E08.621, E08.622, E08.628, E08.630, E08.638, E08.641, E08.649, E08.65, E08.69, E08.8, E08.9, E10.10, E10.11, E10.21, E10.22, E10.29, E10.311, E10.319, E10.3211, E10.3212, E10.3213, E10.3219, E10.3291, E10.3292, E10.3293, E10.3299, E10.3311, E10.3312, E10.3313, E10.3319, E10.3391, E10.3392, E10.3393, E10.3399, E10.3411, E10.3412, E10.3413, E10.3419, E10.3491, E10.3492, E10.3493, E10.3499, E10.3511, E10.3512, E10.3513, E10.3519, E10.3521, E10.3522, E10.3523, E10.3529, E10.3531, E10.3532, E10.3533, E10.3539, E10.3541, E10.3542, E10.3543, E10.3549, E10.3551, E10.3552, E10.3553, E10.3559, E10.3591, E10.3592, E10.3593, E10.3599, E10.36, E10.37X1, E10.37X2, E10.37X3, E10.37X9, E10.39, E10.40, E10.41, E10.42, E10.43, E10.44, E10.49, E10.51, E10.52, E10.59, E10.610, E10.618, E10.620, E10.621, E10.622, E10.628, E10.630, E10.638, E10.641, E10.649, E10.65, E10.69, E10.8, E10.9, E11.00, E11.01, E11.10, E11.11, E11.21, E11.22, E11.29, E11.311, E11.319, E11.3211, E11.3212, E11.3213, E11.3219, E11.3291, E11.3292, E11.3293, E11.3299, E11.3311, E11.3312, E11.3313, E11.3319, E11.3391, E11.3392, E11.3393, E11.3399, E11.3411, E11.3412, E11.3413, E11.3419, E11.3491, E11.3492, E11.3493, E11.3499, E11.3511, E11.3512, E1.13513, E11.3519, E11.3521, E11.3522, E11.3523, E11.3529, E11.3531, E11.3532, E11.3533, E11.3539, E11.3541, E11.3542, E11.3543, E11.3549, E11.3551, E11.3552, E11.3553, E11.3559, E11.3591, E11.3592, E11.3593, E11.3599, E11.36, E11.37X1, E11.37X2, E11.37X3, E11.37X9, E11.39, E11.40, E11.41, E11.42, E11.43, E11.44, E11.49, E11.51, E11.52, E11.59, E11.610, E11.618, E11.620, E11.621, E11.622, E11.628, E11.630, E11.638, E11.641, E11.649, E11.65, E11.69, E11.8, E11.9, E13.00, E13.01, E13.10, E13.11, E13.21, E13.22, E13.29, E13.311, E13.319, E13.3211, E13.3212, E13.3213, E13.3219, E13.3291, E13.3292, E13.3293, E13.3299, E13.3311, E13.3312, E13.3313, E13.3319, E13.3391, E13.3392, E13.3393, E13.3399, E13.3411, E13.3412, E13.3413, E13.3419, E13.3491, E13.3492, E13.3493, E13.3499, E13.3511, E13.3512, E13.3513, E13.3519, E13.3521, E13.3522, E13.3523, E13.3529, E13.3531, E13.3532, E13.3533, E13.3539, E13.3541, E13.3542, E13.3543, E13.3549, E13.3551, E13.3552, E13.3553, E13.3559, E13.3591, E13.3592, E13.3593, E13.3599, E13.36, E13.37X1, E13.37X2, E13.37X3, E13.37X9, E13.39, E13.40, E13.41, E13.42, E13.43, E13.44, E13.49, E13.51, E13.52, E13.59, E13.610, E13.618, E13.620, E13.621, E13.622, E13.628, E13.630, E13.638, E13.641, E13.649, E13.65, E13.69, E13.8, E13.9
Smoking	Aortic aneurysm or dilation
V15.82, 305.1, 649.00, 649.01, 649.02, 649.03, 649.04, 989.84, O99.330, O99.331, O99.332, O99.333, O99.334, O99.335, T65.221A, T65.221D, T65.221S, T65.222A, T65.222D, T65.222S, T65.223A, T65.223D, T65.223S, T65.224A, T65.224D, T65.224S, F17.210, F17.211, F17.213, F17.218, F17.219, Z71.6, Z72.0	93.0, 441.7, 441.2, A52.01, I71.2, I71.6, Q25.43, Q25.44, 447.71, 447.73, I77.810, I77.812
Coronary artery bypass	Right ventricle to pulmonary artery conduit
36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19, 210093, 02100A3, 02100J3, 02100K3, 02100Z3, 210493, 02104A3, 02104J3, 02104K3, 02104Z3, 021009W, 02100AW, 02100JW, 02100KW, 021049W, 02104AW, 02104JW, 02104KW, 021109W, 02110AW, 02110JW, 02110KW, 021149W, 02114AW, 02114JW, 02114KW, 021209W, 02120AW, 02120JW, 02120KW, 021249W, 02124AW, 02124JW, 02124KW, 021309W, 02130AW, 02130JW, 02130KW, 021349W, 02134AW, 02134JW, 02134KW, 210098, 210099, 021009C, 02100A8, 02100A9, 02100AC, 02100J8, 02100J9, 02100JC, 02100K8, 02100K9, 02100KC, 02100Z8, 02100Z9, 02100ZC, 0210498, 0210499, 021049C, 02104A8, 02104A9, 02104AC, 02104J8, 02104J9, 02104JC, 02104K8, 02104K9, 02104KC, 02104Z8, 02104Z9, 02104ZC, 0211098, 0211099, 021109C, 02110A8, 02110A9, 02110AC, 02110J8, 02110J9, 02110JC, 02110K8, 02110K9, 02110KC, 02110Z8, 02110Z9, 02110ZC, 0211498, 0211499, 021149C, 02114A8, 02114A9, 02114AC, 02114J8, 02114J9, 02114JC, 02114K8, 02114K9, 02114KC, 02114Z8, 02114Z9, 02114ZC, 021209C, 02120AC, 02120JC, 02120KC, 02120ZC, 021249C, 02124AC, 02124JC, 02124KC, 02124ZC, 021309C, 02130AC, 02130JC, 02130KC, 02130ZC, 021349C, 02134AC, 02134JC, 02134KC, 02134ZC, 021009F, 02100AF, 02100JF, 02100KF, 02100ZF, 021049F, 02104AF, 02104JF, 02104KF, 02104ZF, 0210093, 02100A3, 02100J3, 02100K3, 02100Z3, 0210493, 02104A3, 02104J3, 02104K3, 02104Z3	35.92, 021K09P, 021K09Q, 021K09R, 021K0AP, 021K0AQ, 021K0AR, 021K0JP, 021K0JQ, 021K0JR, 021K0KP, 021K0KQ, 021K0KR, 021K0ZP, 021K0ZQ, 021K0ZR, 021K49P, 021K49Q, 021K49R, 021K4AP, 021K4AQ, 021K4AR, 021K4JP, 021K4JQ, 021K4JR, 021K4KP, 021K4KQ, 021K4KR, 021K4ZP, 021K4ZQ, 021K4ZR, 021L0ZW, 021L4ZW

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Outcomes	
Permanent pace maker	Temporary pacing
50, 53, 37.80, 37.81, 37.82, 37.83, 02H40JZ, 02H40NZ, 02H43JZ, 02H43NZ, 02H44JZ, 02H44NZ, 02H60JZ, 02H60NZ, 02H63JZ, 02H63NZ, 02H64JZ, 02H64NZ, 02H70JZ, 02H70NZ, 02H73JZ, 02H73NZ, 02H74JZ, 02H74NZ, 02HK0JZ, 02HK0NZ, 02HK3JZ, 02HK3NZ, 02HK4JZ, 02HK4NZ, 02HL0JZ, 02HL0NZ, 02HL3JZ, 02HL3NZ, 02HL4JZ, 02HL4NZ, 02HN0JZ, 02HN3JZ, 02HN4JZ, 0JH604Z, 0JH605Z, 0JH606Z, 0JH607Z, 0JH634Z, 0JH635Z, 0JH636Z, 0JH637Z, 0JH804Z, 0JH805Z, 0JH806Z, 0JH807Z, 0JH834Z, 0JH835Z, 0JH836Z, 0JH837Z	37.78, 5A1213Z, 5A1223Z
Ventricular assist device	Temporary mechanical circulatory support
02HA0QZ, 02HA3QZ, 02HA4QZ, 37.52, 37.66	5A02116, 5A0211D, 5A02216, 5A0221D, 02HA3RZ, 37.68, 02HA0RS, 02HA3RS, 02HA4RS, 5A02116, 5A02216, 02HA0RZ, 02HA4RZ, 5A02216, 37.60, 37.65
Extracorporeal membrane oxygenation	Ventilator support > 96 hours
5A15223, 5A1522F, 5A1522G, 5A1522H, 39.65	5A1955Z, 96.72
Acute renal failure	
N17.0, N17.1, N17.2, N17.8, N17.9, 584.5, 584.6, 584.7, 584.8, 584.9	

Figure S1 ICD 9/10 diagnosis and procedure codes utilized to identify diagnoses and procedures analyzed.

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