Isolated Mitral Valve Surgery: The Society of Thoracic Surgeons Adult Cardiac Surgery Database Analysis

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Background. **Data from The Society of Thoracic Surgeons Adult Cardiac Surgery Database were analyzed to identify trends in patient characteristics and outcomes of mitral valve operations in North America.**

Methods. **All patients with isolated primary mitral valve operations with or without tricuspid valve repair, surgical atrial fibrillation ablation, or atrial septal defect closure performed July 2011 to September 2016 were identified. A subgroup analysis assessed patients with degenerative leaflet prolapse (DLP).**

Results. **Isolated primary mitral valve operations were performed on 87,214 patients at 1,125 centers, increasing by 24% between 2011 (n = 14,442) and 2016 (n = 17,907). The most common etiology was DLP (60.7%); 4.3% had functional mitral regurgitation. Preoperatively, 47.3% of patients had an ejection fraction less than 60% and 34.2% had atrial fibrillation. Overall mitral valve repair rate was 65.6%, declining from 67.1% (2011) to 63.2% (2016; $p < 0.0001$). Repair rates were related to etiology (DLP, 82.5%; rheumatic, 17.5%). Of the 29,970 mitral valve replacements, 16.2% were preceded by an attempted repair. Repair techniques included prosthetic annuloplasty (94.3%), leaflet resection (46.5%), and artificial cord implantation (22.7%). Bioprosthetic valves were implanted with increasing frequency (2011, 65.4%; 2016, 75.8%; $p < 0.0001$). Less-invasive operations were performed in 23.0% and concomitant tricuspid valve repair in 15.7%. Unadjusted operative mortality was 3.7% (replacements) and 1.1% (repairs).**

Conclusions. **Patients undergoing primary isolated mitral valve operations commonly have ventricular dysfunction, atrial fibrillation, and heart failure. Although contemporary outcomes are excellent, earlier guideline-directed referral and increased frequency and quality of repair may further improve results of mitral valve operations.**

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Mitral valve (MV) surgery alleviates symptoms of heart failure, prevents or reverses ventricular remodeling, and decreases mortality in patients with severe MV disease. Contemporary trends in the therapy of patients with MV disease include an enhanced understanding of the benefits of timely referral for operation [1, 2], acknowledgment of the superiority of repair compared with replacement for degenerative mitral regurgitation [3, 4], and

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Abbreviations and Acronyms

ACSD	=	Adult Cardiac Surgery Database
AF	=	atrial fibrillation
AV	=	aortic valve
DLP	=	degenerative leaflet prolapse
IQR	=	interquartile range
LVEF	=	left ventricular ejection fraction
MR	=	mitral regurgitation
MV	=	mitral valve
NYHA	=	New York Heart Association
O/E	=	observed to expected
PROM	=	predictive risk of mortality
sPAP	=	systolic pulmonary artery pressure
STS	=	The Society of Thoracic Surgeons

improved operative outcomes [3]. The Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database (ACSD) data elements were updated in 2011 to provide a more complete and accurate assessment of MV disease etiology as well as operative therapy, and outcomes. The STS ACSD was examined to document contemporary patient characteristics, operative approaches, and clinical outcomes of patients undergoing MV operations in North America.

Material and Methods

The STS ACSD is a repository for more than 6.1 million surgical records, encompassing voluntarily reported data from more than 90% of all adult cardiac surgery centers in the United States [5, 6]. Research performed at the Duke Clinical Research Institute on the STS database was approved by the Duke University Institutional Review Board and was granted a waiver of informed consent and Health Information Portability and Accountability Act authorization. Principal investigators at participating institutions are responsible for reviewing their data collection efforts with their sites' Institutional Review Boards to ensure that patient privacy and confidentiality is protected.

Patient Population

Patients who underwent primary isolated MV operations between July 1, 2011, and September 30, 2016, were identified in the STS ACSD (v.2.73 and 2.81). Data on the number and type of procedures from 2011 (6 months of available data) and 2016 (9 months of available data) were normalized to 12 months for volume trend analyses. Isolated MV operations were defined as those without concomitant coronary artery bypass graft surgery or aortic valve (AV) procedure and with or without tricuspid valve repair, surgical ablation of atrial fibrillation (AF), or atrial septal defect closure. Patients with a history of prior cardiac procedure, emergent or emergent/salvage status, shock, or active infective endocarditis were excluded.

From the full cohort of patients undergoing isolated primary MV operations, a hierarchical classification system was used to identify the etiologies underlying the associated MV disease [7]. Etiologies were not mutually exclusive. Because at least one and as many as three etiologies could be selected in the data classification forms, etiology was assigned sequentially, beginning with treated endocarditis, followed by rheumatic disease, uncommon diseases (tumor, hypertrophic obstructive cardiomyopathy, trauma, and congenital), ischemic disease, nonischemic cardiomyopathy, degenerative leaflet prolapse (DLP), pure annular dilation, and other/unknown.

Patients with DLP, defined as those having Carpentier class II dysfunction and/or leaflet prolapse (anterior, posterior, and/or bileaflet) and/or elongated or ruptured chords, and excluding patients with endocarditis, stenosis, rheumatic disease, tumor, hypertrophic obstructive cardiomyopathy, trauma, congenital disease, and ischemic disease were separately analyzed for outcomes and repair rates.

Definitions

Active infective endocarditis, congestive heart failure, prior heart failure, and mitral regurgitation (MR) were previously defined [8]. Mitral regurgitation was reported as none, trivial/trace, mild, moderate, severe, or not documented, based on the American Society of Echocardiography guidelines [9]. All MR grades were site-determined. Mitral regurgitation scores of "none" and "trivial/trace" were combined into a single variable (none/trace) for the purposes of this analysis. Less invasive MV operations were defined as those done through a limited minithoracotomy, port access, and right thoracotomy, as well as those identified as minimally invasive or robotic technology assisted. The STS predictive risk of operative mortality (PROM) score was calculated based on the published STS 2007 risk model for isolated valve surgery [10].

Indications for MV surgery were defined [2, 11] as class I symptomatic (severe MR with symptoms), class I asymptomatic (severe MR and left ventricular ejection fraction [LVEF] of 30% to 60% and/or a left ventricular end-systolic dimension of 40 mm or more, with no symptoms), class IIa asymptomatic without triggers (severe MR and LVEF greater than 60% and left ventricular end-systolic dimension less than 40 mm), and class IIa asymptomatic with triggers (severe MR and LVEF greater than 60% and left ventricular end-systolic dimension less than 40 mm and either AF and/or pulmonary artery systolic pressure [sPAP] greater than 50 mm Hg).

Statistical Analysis

Statistical analyses (SAS statistical software v.9.4; SAS Institute, Cary, NC) included χ^2 tests for categoric variables, Cochran-Armitage trend tests for tests of trend, and Wilcoxon tests for continuous variables. Because the DLP group was a subgroup of the overall cohort, applicable mean comparisons were done between the DLP group and the portion of the overall cohort not containing the DLP patients. All other mean comparisons were calculated between the repair and replacement subsets of the respective parent grouping (overall or DLP).

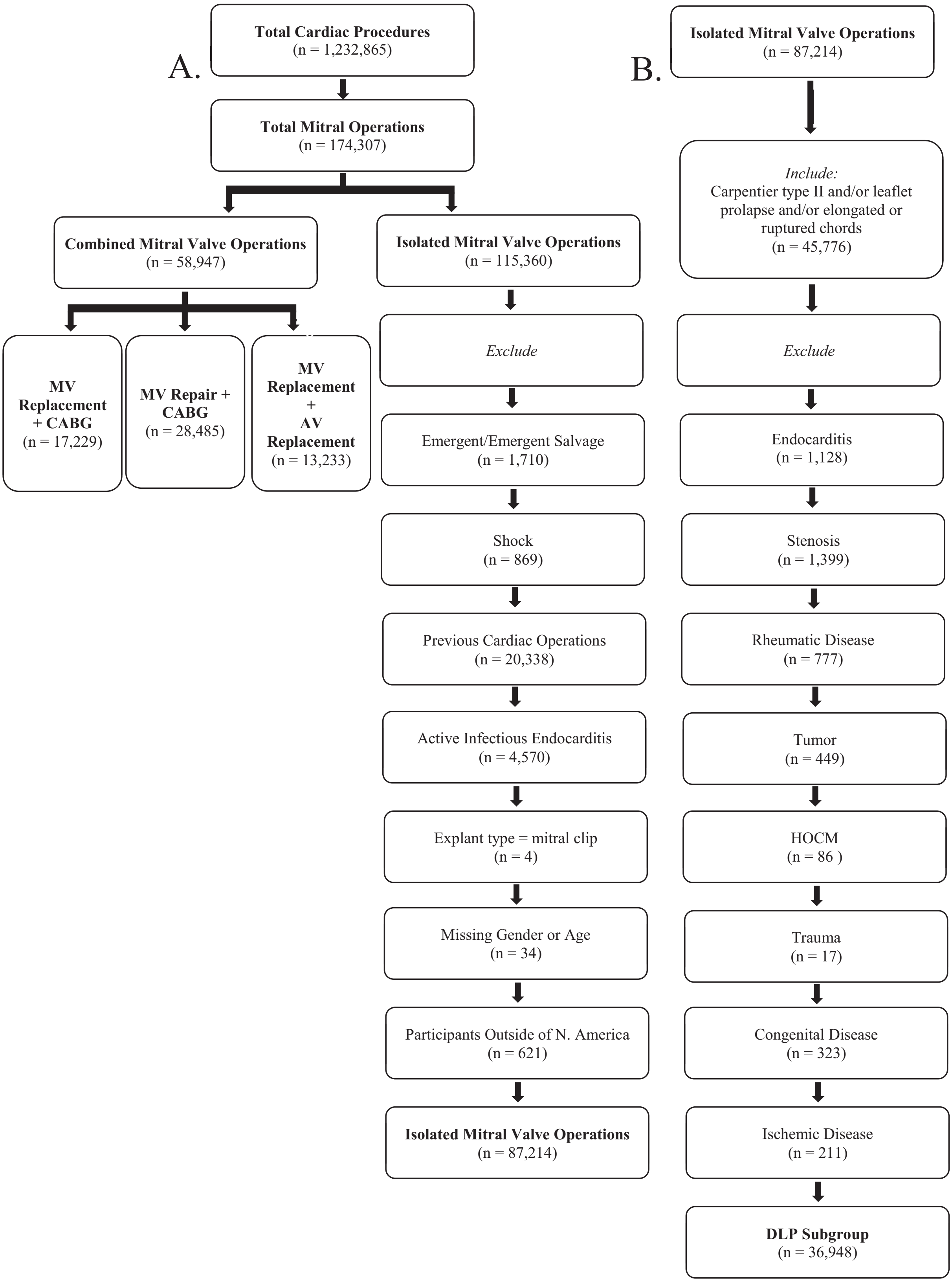

Fig 1. (A) Consolidated Standards of Reporting Trials (CONSORT) flow diagram demonstrating selection of patients undergoing isolated primary mitral valve operations. Total cardiac procedures includes coronary artery bypass graft surgery (CABG), aortic valve (AV) replacement, AV repair, mitral valve (MV) replacement, MV repair, AV replacement plus CABG, MV replacement plus CABG, MV repair plus CABG, and AV replacement plus MV replacement. (B) Consort diagram demonstrating the selection of patients with degenerative leaflet prolapse (DLP) subgroup.

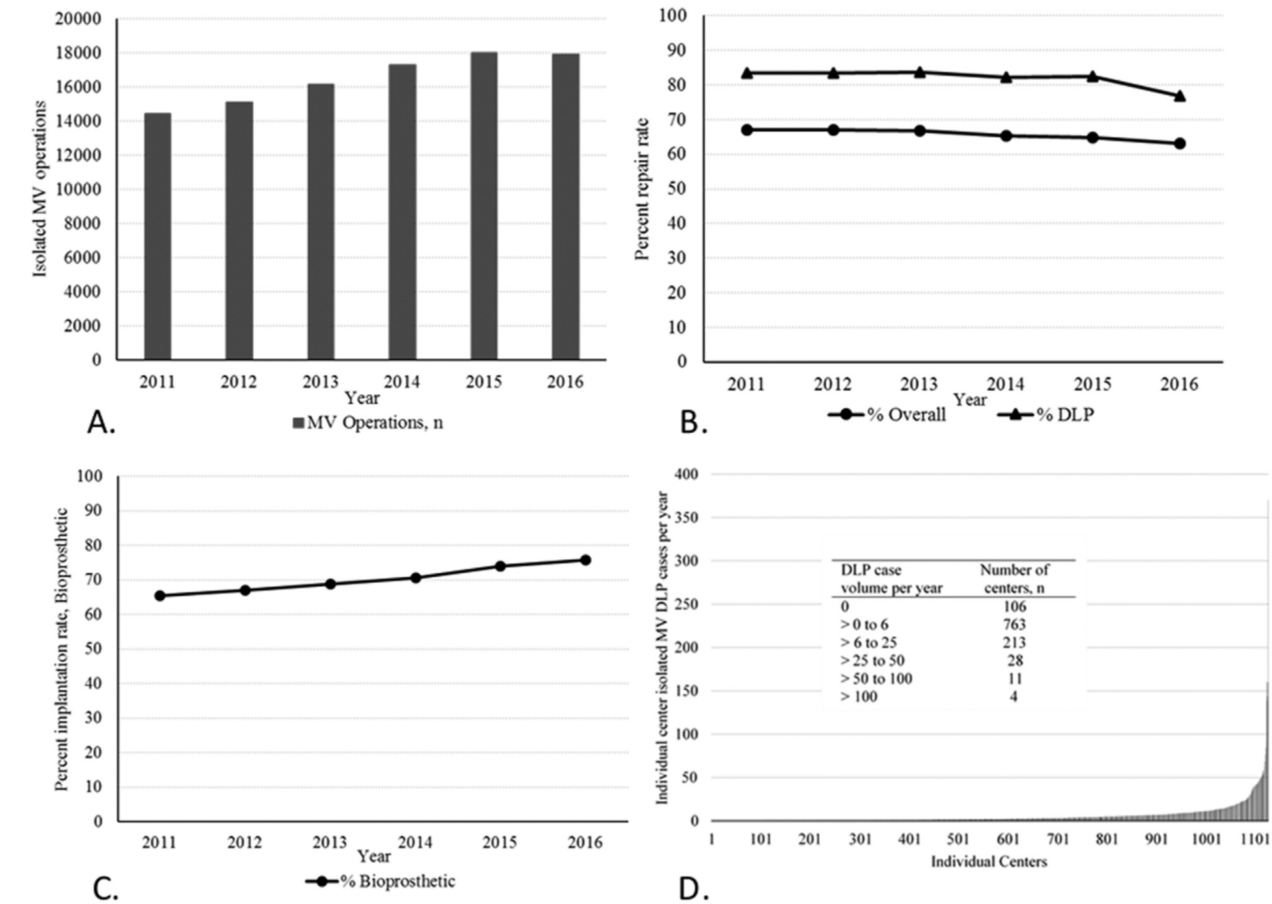

Fig 2. (A) Number of isolated primary mitral valve (MV) operations performed at 1,143 participating institutions on a monthly basis between July 1, 2011, and September 30, 2016. Data from 2011 (6 months) and 2016 (9 months) were normalized to 12 months. (B) Isolated primary mitral valve repair rates between 2011 and 2016 for all patients (overall cohort) and patients with degenerative leaflet prolapse (DLP) undergoing isolated primary mitral valve operations. (C) Rate of bioprosthetic valve implantation for all patients undergoing mitral valve replacement. (D) Center volume per year for patients undergoing isolated primary mitral valve operations between 2011 and 2016.

Results

During the study period (July 1, 2011, to September 30, 2016), 115,360 MV operations were performed at 1,143 participating institutions. The number of sites reporting each year was consistent (1,015 in 2011 and 1,061 in 2016). After application of exclusion criteria (Fig 1A), the final patient total (overall cohort) was 87,214 primary isolated MV operations from 1,125 institutions. Of the 1,125 sites, 722 (64.2%) reported data for all 6 study years. From the overall cohort, 45,776 patients with Carpentier type II dysfunction or leaflet prolapse or elongated or ruptured chords were identified. After further application of exclusion criteria (Fig 1B), 36,946 patients were assigned to the DLP subgroup. Between 2011 and 2016, the number of isolated MV operations performed per year increased from 14,442 in 2011 to 17,907 in 2016 (24% increase; $p < 0.0001$; Fig 2A), a compounded annual growth rate of 4.4%. Isolated MV procedures in the DLP group increased by 44%, from 5,678 in 2011 to 8,180 in 2016 (7.6% compounded annual growth rate). In contrast, the total number of all cardiac procedures in the STS ACSD increased by 11%, from 219,052 in 2011 to 243,397 in 2016 (2.1% compounded annual growth rate). Total aortic valve operations (isolated and combined) during the period studied numbered 283,767, whereas total MV operations (isolated and combined) numbered 174,307. Operations

Table 1. Hierarchical Assessment of Etiologies Underlying Mitral Valve Disease and Proportion of Patients Undergoing Isolated Primary Mitral Valve Repair or Replacement Within Each Etiology Between 2011 and 2016

Etiology	Patients (n = 87,214)	Repair (%)	Replace (%)
Degenerative leaflet prolapse	36,554	82.7	17.3
Rheumatic disease	13,545	17.5	82.5
Endocarditis	3,085	48.1	51.9
Pure annular dilation	2,265	84.9	15.1
Uncommon diseases	2,219	68.2	31.8
Nonischemic cardiomyopathy	1,731	66.0	34.0
Ischemic disease	785	58.2	41.8
Unknown	27,029	67.0	33.0

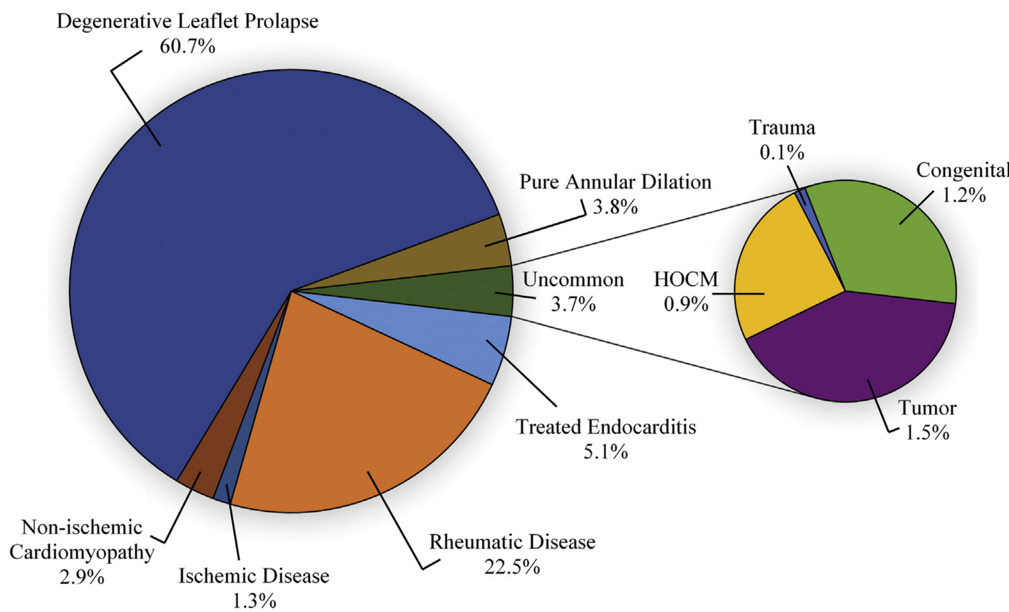

Fig 3. Proportion of patients undergoing isolated primary mitral valve operations (overall group) between 2011 and 2016 for each underlying etiology of mitral valve disease. The proportions were calculated from a subset of patients with known etiology (n = 60,185; unknown etiology = 31%; 27,029 of 87,214 patients). (HOCM = hypertrophic obstructive cardiomyopathy.)

with a MV component (combined and isolated) represented 14.1% of all cases recorded in the STS ACSD, whereas 22.9% of operations included an AV component.

Etiology of MV Disease

An etiology was reported for 69% of patients (60,185 of 87,214). For patients with a reported etiology (n = 60,185), DLP was present in 60.7%, rheumatic etiology in 22.5%,

Table 2. Characteristics of All Patients and Patients With Degenerative Leaflet Prolapse Undergoing Isolated Primary Mitral Valve Operations Between 2011 and 2016

	Overall			DLP		
Variable	All Patients (n = 87,214)	Repair (n = 57,244)	Replacement (n = 29,970)	All Patients (n = 36,948)	Repair (n = 30,490)	Replacement (n = 6,458)
Age, years[a]	64 (55–73)	63 (54–71)	66 (56–75)	63.0 (55–72)	62.0 (54–70)	69.0 (60–78)
Female	50.1	42.7	64.2	38.3	36.1	48.5
Diabetes mellitus	15.4	11.7	22.5	9.5	8.1	16.4
Chronic lung disease, mild	11.3	9.5	14.8	8.7	8.0	12.0
Chronic lung disease, moderate	5.2	3.9	7.7	3.5	2.9	6.1
Chronic lung disease, severe	3.9	2.6	6.4	2.4	1.9	4.9
Hypertension	66.2	62.5	73.5	60.7	58.2	72.4
Ejection fraction <60	47.3	45.3	51.2	40.3	38.6	48.2
Ejection fraction	50 (53–63)	60 (53–64)	58 (50–63)	60 (55–65)	60 (55–65)	60 (52–63)
LV systolic dimension[b], mm	34.0 (29–40)	35.0 (30–40)	33.0 (28–39)	34.0 (30–39)	34.0 (30–39)	34.0 (29–40)
LV end-diastolic dimension, mm	52.9 (47–58)	54.0 (48–59)	50.0 (44–56)	54.0 (49–59)	54.0 (49–59)	53.0 (47–58)
sPAP[c], mm Hg	40.0 (31–52)	37.0 (29–48)	45.0 (35–59)	36.0 (29–48)	35.0 (28–46)	42.0 (32–54)
Procedure status urgent	17.8	13.7	25.6	13.3	11.2	22.9
Atrial fibrillation[d]	34.4	30.4	42.2	28.5	25.7	41.4
AF, continuous/persistent	18.5	15.9	23.5	14.2	12.4	22.7
AF, paroxysmal	15.7	14.3	18.4	14.2	13.2	18.6
STS PROM score[a], %	1.2 (0.6–2.6)	0.8 (0.4–1.5)	2.6 (1.4–4.7)	0.8 (0.4–1.7)	0.7 (0.4–1.2)	2.5 (1.4–4.6)

[a] Calculated from the overall cohort (87,214 patients). [b] For the degenerative leaflet prolapse (DLP) subgroup, no significant difference was found between DLP patients undergoing repair or replacement ($p = 0.8384$); left ventricular (LV) end-systolic dimension was calculated from a subset of 45,089 patients, and LV end-diastolic dimension was calculated from a subset of 44,460 patients. [c] Systolic pulmonary artery pressure (sPAP) was calculated from a subset of 52,322 patients. [d] Atrial fibrillation (AF) was present in 30,011 patients (overall cohort), 17,367 of whom underwent repairs and 12,644 underwent replacement; AF was present in 10,513 DLP patients, 7,841 of whom underwent repairs and 2,672 underwent replacement.

Values are median (interquartile range) or percentage. All mean comparisons for repair and replacement within each data grouping (overall and degenerative leaflet prolapse [DLP]) were significant ($p < 0.0001$) unless otherwise indicated.

STS PROM = The Society of Thoracic Surgeons predicted risk of mortality.

and functional (ischemic or nonischemic) MR in 4.2% (Table 1, Fig 3). Repair or replacement rates as a function of etiology are presented in Table 1.

Preoperative Characteristics

The average age of patients in the overall cohort undergoing isolated primary MV operations was 64 years (interquartile range [IQR]: 55 to 73) and half were female (Table 2). Patients undergoing MV replacement compared with repair were slightly older, more likely to be female, and had increased rates of diabetes mellitus, chronic lung disease, and hypertension. The median STS PROM score was 1.2% (IQR: 0.6% to 2.6%). Patients undergoing MV repair had a median STS PROM score of 0.8% (IQR: 0.4% to 1.5%), whereas patients undergoing MV replacements had a median PROM score of 2.6% (IQR: 1.4% to 4.7%).

The median LVEF was 60% (60% in repair patients and 58% in replacement patients). Almost half of patients (47.3%; 40,304 of 85,188) had a preoperative ejection fraction less than 60%. Preoperative AF was present in 34.4% of all patients (30,011 of 87,214). Mitral stenosis was present in 12.1% of patients (10,368 of 87,214; 30.6% of replacements and 2.4% of repairs), with a median gradient of 12.0 mm Hg (IQR: 8.0 to 16.0 mm Hg, calculated from a subset of 7,614 patients). Median preoperative sPAP was 40 mm Hg (IQR: 31 to 52 mm Hg; Table 2). Of patients for whom sPAP was measured (n = 52,194), 48.% (25,189 of 52,194) had sPAP less than 40 mm Hg, whereas 24.2% (12,607 of 52,194) had sPAP between 40 mm Hg and 50 mm Hg, and 27.6% (14,398 of 52,194) had sPAP greater than 50 mm Hg.

Overall, 58.1% of patients (50,645 of 87,214) were reported to have a preoperative history of congestive heart failure. Congestive heart failure during the 2 weeks before surgery was present in 48.8% of patients (42,578 of 87,214), with 6.51% (2,773 of 42,578) classified as New York Heart Association (NYHA) I, 31.2% (13,272 of 42,578) classified as NYHA II; 42.3% (18,024 of 42,578) classified as NYHA III; and 17.7% (7,536 of 42,578) classified as NYHA IV (missing data, 2.29%, 973 of 42,578).

The DLP subgroup (42.4%, 36,948 of 87,214) was similar to the overall group in patient characteristics (Table 2) but included fewer women (38.3% female versus 50.1% female in overall group), less diabetes, lung disease, and hypertension. The median PROM score for patients in the DLP group was 0.8%, IQR: 0.4% to 1.7%) and the median LVEF was 60%. Preoperative AF was present in 28.5% (10,513 of 36,948) and 40.3% of patients (14,606 of 36,279) had LVEF less than 60%. Of the DLP patients where the specific prolapse location was identified (n = 19,997 of 36,948), posterior leaflet prolapse was present in 64.8% of patients (12,961 of 19,997), bileaflet prolapse in 26.3% (5,214 of 19,997), and anterior leaflet prolapse in 10.6% (2,034 of 19,997).

Median preoperative sPAP for the DLP group was 36 mm Hg (IQR: 29 to 48 mm Hg). Of DLP patients for whom sPAP was measured (n = 21,804 of 36,948), 57.2% (12,466 of 21,804) had sPAP less than 40 mm Hg, 22.1% (4,815 of 21,804) had sPAP between 40 and 50 mm Hg, and 10% (2,189 of 21,804) had sPAP greater than 50 mm Hg.

Indications for operation in the DLP group are presented in Table 3. Overall, 76.2% of patients had class I indications for operation, with nearly half having preserved ventricular function with symptoms. More than a quarter of patients had symptoms and LVEF less than 60%, and nearly 10% were asymptomatic with preserved ventricular function.

Operative Characteristics

The majority of patients (74.1%; 64,592 of 87,214) underwent conventional sternotomy, whereas 23% (20,069 of 87,214) underwent less invasive surgical approaches (Table 4). Robotic-assisted technology was reported in 8% of procedures (6,998 of 87,214). In the DLP subgroup, less invasive surgical approaches were utilized in 29.1% of cases (10,756 of 36,948) and robotic procedures used in

Table 3. Indications for Mitral Valve Surgery for Patients With Degenerative Leaflet Prolapse

	Overall (n = 31,475)[a]		Repair (n = 25,765)		Replace (n = 5,710)	
Indications	n	%	n	%	n	%
Class I, symptomatic	17,901	56.9	13,938	54.1	3,963	69.4
Severe MR						
Class I, asymptomatic	10,247	32.6	8,820	34.2	1,427	25
Severe MR and LVEF ≤ 60% or LVESD ≥40 mm						
Class IIa, asymptomatic, no triggers[b]	2,661	8.5	2,451	9.5	210	3.7
Severe MR and LVEF > 60% and LVESD <40 mm						
Class IIa, asymptomatic, with triggers[bc]	666	2.1	556	2.2	110	1.9
Severe MR and LVEF > 60% and LVESD <40 mm (and AF and/or sPAP >50 mm Hg)						

[a] Data on indications for mitral valve surgery were available for 85.2% of overall patients (31,475 of 36,948), 84.5% of repair patients (25,765 of 30,490), and 88.4% of replacement patients (5,710 of 6,458). [b] Triggers: either atrial fibrillation (AF) or systolic pulmonary artery pressure >50 mm Hg. [c] Repair versus replace, $p = 0.5094$.

All categoric row variable mean comparisons were significant ($p < 0.0001$) unless otherwise indicated.

LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic dimension; MR = mitral regurgitation; sPAP = systolic pulmonary artery pressure.

Table 4. Operative Characteristics of All Patients and Patients With Degenerative Leaflet Prolapse Undergoing Isolated Primary Mitral Valve Operations Between 2011 and 2016

	Overall			DLP		
Operative Characteristics	All Patients (n = 87,214)	Repair (n = 57,244)	Replacement (n = 29,970)	All Patients (n = 36,948)	Repair (n = 30,490)	Replacement (n = 6,458)
Surgical access						
Sternotomy	74.1	68.2	85.3	67.5	64.0	84.5
Less-invasive operations	23.0	28.4	12.9	29.1	32.4	13.6
Limited minithoracotomy (right)	4.3	5.1	2.9	5.6	6.0	3.6
Right thoracotomy	10.7	13.0	6.4	13.4	14.8	6.9
Minimally invasive	6.3	8.1	3.0	7.6	8.7	2.8
Port access	1.6	2.1	0.5	2.4	2.8	0.3
Robotic technology assisted[a]	8.0	11.5	1.4	12.1	14.4	1.2
Other access	3.0	3.5	1.9	3.5	3.7	1.9
Missing	0.3	0.3	0.3	0.1	0.1	0.1
Procedural times						
Perfusion time, minutes	117 (90–151)	115 (88–148)	122 (95–159)	118 (91–152)	116 (89–149)	126 (98–171)
Cross-clamp time, minutes	85 (65–112)	83 (63–108)	90 (69–119)	86 (66–113)	85 (65–100)	95 (72–130)
Operative characteristics, tricuspid	(n = 13,661)	(n = 8,379)	(n = 5,282)	(n = 4,470)	(n = 3,505)	(n = 985)
Tricuspid procedure	15.7	14.6	17.6	12.1	11.5	14.9
Annuloplasty	90.1	90.9	89.0	91.5	91.9	90.1
Prosthetic	83.2	83.6	82.5	83.6	83.7	83.3
Pericardium	7.0	6.4	7.9	7.1	7.0	7.4
Suture	0.3	0.3	0.2	0.3	0.3	0.2
Reconstruction with annuloplasty	8.6	8.0	9.4	7.5	7.3	8.1
Reconstruction without annuloplasty	1.3	1.1	1.6	1.0	0.8	1.9
Operative characteristics, AF	(n = 30,011)	(n = 17,367)	(n = 12,644)	(n = 10,513)	(n = 7,841)	(n = 2,672)
Ablation in patients with preoperative AF						
No AF procedure	13.4	12.0	15.3	12.1	11.0	15.2
AF ablation	51.2	55.9	44.9	54.4	57.6	45.1
Missing	35.4	32.1	39.8	33.5	31.3	39.8

[a] Because the numbers of less-invasive operations that also utilized robotic technology were not recorded in The Society of Thoracic Surgeons Adult Cardiac Surgery Database, “robotic technology-assisted procedures” is not a mutually exclusive variable, causing the surgical access total percentage to sum to more than 100%. In the global group, 6,998 of 87,214 patients underwent robotic-assisted procedures (mitral repair, 6,587 of 57,244; mitral replacement 411 of 29,970 patients). In the DLP group, 4,479 of 36,948 patients underwent robotic-assisted procedures (mitral repair, 4,404 of 30,490; mitral replacement 75 of 6,458).

Values are percent or median (interquartile range). “Other access” included partial sternotomy, right or left parasternal incision, left thoracotomy, transverse sternotomy/clamshell, subxiphoid, subcostal, bilateral thoracotomy, limited minithoracotomy (bilateral), percutaneous, none (cancelled case), or other (undefined). All mean comparisons for repair and replacement within each data grouping (overall and degenerative leaflet prolapse [DLP]) were significant ($p < 0.0001$) unless otherwise indicated.

AF = atrial fibrillation.

Table 5. Mitral Valve Repair Techniques for All Patients and Patients With Degenerative Leaflet Prolapse Undergoing Mitral Valve Repair Operations Between 2011 and 2016

Variable	Repairs Overall (n = 57,244)	Repairs DLP (n = 30,490)
Annuloplasty[a]	94.3	96.1
Ring	68.9	68.5
Band	19.4	24.9
Other/missing	6.0	6.6
Leaflet resection[b], all	46.5	58.9
Triangular	24.9	32.7
Quadrangular	16.8	21.3
Other/missing	4.8	4.9
Leaflet resection location		
Anterior	1.6	1.5
Posterior	42.3	54.9
Both	1.9	1.9
Missing	0.6	0.6
Mitral sliding valvuloplasty	10.0	13.4
Mitral annular decalcification	1.2	1.2
Artificial ePTFE cords	22.7	29.2
Number of artificial ePTFE cords[c]	2.0 (2.0–4.0)	2.0 (2.0–4.0)
Mitral chordal/leaflet transfer	2.9	3.5
Mitral leaflet extension/ replacement/patch	1.8	1.1
Edge-to-edge	5.8	6.2
Combined resection/chordal	1.8	2.3

[a] Of the 53,980 patients receiving an annuloplasty (overall cohort; 94.3%), 39,428 received a band and 39,428 received a ring. For the DLP subgroup, of the 29,312 patients receiving an annuloplasty (96.1%), 7,607 received a band and 20,970 received a ring. [b] Of the 26,592 patients receiving mitral leaflet resection (overall cohort; 46.5%), 14,238 underwent triangular resection and 9,588 underwent quadrangular resection of the anterior leaflet (941 patients), posterior leaflet (24,216 patients), or both (1,085 patients). For the DLP subgroup, of the 17,957 patients receiving mitral leaflet resection (58.9%), 9,973 underwent triangular resection and 6,478 underwent quadrangular resection of the anterior leaflet (449 patients), posterior leaflet (16,756 patients), or both (585 patients). [c] Artificial expanded polytetrafluoroethylene (ePTFE) cord number was calculated from 12,715 patients (overall) and 8,766 patients (DLP).

Values are percentage or median (interquartile range). All mean comparisons within each data grouping (overall and degenerative leaflet prolapse [DLP]) were significant ($p < 0.0001$) unless otherwise indicated.

12.1% (4,479 of 36,948). Among the 30,011 patients diagnosed with preoperative AF, 51.2% (15,377 of 30,011) had a concomitant surgical ablation procedure. In the DLP group, 54.4% of patients (5,721 of 10,513) with AF underwent surgical ablation. Operative characteristics are reported in Table 4.

Mitral Valve Repair

The overall MV repair rate was 65.6% (57,244 of 87,214) for patients undergoing isolated MV operations. Overall repair rates decreased from 67.1% (4,842 of 7,221) in 2011 to 63.2% (8,486 of 13,430) in 2016 ($p < 0.0001$; Fig 2B). The MV repair rate for DLP patients was 82.5% (30,490 of 36,948). The DLP MV repair rates declined slightly from 83.5% (2,369 of 2,839) in 2011 to 80.7% (4,949 of 6,135) in 2016 ($p < 0.0001$; Fig 2B). The MV repair techniques are presented in Table 5. The etiology of MV disease had an important impact on repair rates, with relatively high rates of repair for patients with DLP and pure annular dilation, and low repair rates for patients with rheumatic disease.

Mitral Valve Replacement

Mitral valve replacement was performed at a rate of 34.4% overall (29,970 of 87,214) and 17.5% in the DLP group (6,485 of 36,948). Among patients undergoing MV replacement, bioprosthetic (as compared with mechanical) valves were implanted in 70.8% (21,215 of 29,970). The majority of bioprosthetic valves were porcine (59.3%; 12,580 of 21,215) versus bovine pericardial (40.7%; 8,635 of 21,215). The proportion of patients receiving bioprosthetic valves increased over time ($p < 0.0001$; Fig 2C). When replacement was performed in DLP patients, 79.7% (5,147 of 6,458) received bioprosthetic valves.

Among all patients with isolated MV operations, 5.6% (4,864 of 87,214) had an attempted repair followed by a replacement (during the same operation); in the DLP group, 4.8% (1,771 of 36,948) of all operations resulted in a replacement after an unsuccessful repair. Of all 29,970 MV replacements in the overall group, 16.2% (4,864 of 29,970) were preceded by an unsuccessful attempt at repair, and of the 6,548 MV replacements in the DLP group, 27.4% (1,771 of 6,548) were preceded by an unsuccessful attempt at repair.

Outcomes

Overall operative mortality was 2.0% (1,762 of 87,214), and it was 1.2% (443 of 36,948) in the DLP group (Table 6). Mitral valve replacement was consistently associated with higher unadjusted operative mortality. Key morbidities are presented in Table 6. Postprocedure transesophageal echocardiography was performed in 82.6% of all cases (71,998 of 87,214), with increasing utilization from 77.5% in 2011 to 88.6% in 2016. Postoperative transthoracic echocardiography was performed in 34.3% of all cases (29,889 of 87,214). Reported preoperative, intraoperative, and predismissal MR grades are given in Supplemental Table 1.

For the overall cohort, 44 centers averaged 50 or more isolated MV operations per year. Of the highest volume centers, 577 performed between six and 50 operations per year, 35 performed 51 to 100 operations per year, 5 performed 101 to 150 operations per year, one performed between 151 and 200 operations per year (189 operations), two centers performed between 201 and 250 operations per year (207 and 242 operations), and the highest volume center performed 462 isolated MV operations per year. Isolated primary MV surgical volume per center per year for DLP cases is shown in Figure 2D. Of the 1,125 centers performing MV operations for DLP, 77.2% (869 of 1,125) performed six or fewer isolated MV operations per year, 13% (147 of 1,125) performed 10 or more per year, and only 15 centers averaged 50 or more isolated MV DLP operations per year. The MV repair rates within the DLP

Table 6. Select Operative Outcomes for All Patients and Patients With Degenerative Leaflet Prolapse Undergoing Isolated Primary Mitral Valve Operations Between 2011 and 2016

	Overall			DLP		
Variable, %	All Patients n = 87,214	Repair n = 57,244	Replacement n = 29,970	All Patients n = 36,948	Repair n = 30,490	Replacement n = 6,458
Reoperation, bleeding/tamponade	2.8	2.1	4.1	2.5	2.0	4.7
Reoperation, valve dysfunction	0.3	0.3	0.2	0.3[b]	0.3	0.3
Reoperation for other cardiac reason	1.0	0.7	1.4	0.8	0.6	1.4
Reoperation for noncardiac reason	1.6	1.1	2.4	1.1	0.9	2.1
Deep sternal wound infection	0.1	0.1	0.2	0.1[c]	0.1	0.2
Permanent stroke	1.3	1.1	1.7	1.1	1.0	1.7
Renal failure	2.1	1.4	3.4	1.2	0.9	3.0
Renal failure with newly acquired dialysis[a]	1.3	0.9	2.2	0.7[d]	0.5	1.7
Rhythm disturbance requiring PPM	5.9	3.8	9.8	4.4	3.1	10.5
Cardiac arrest	1.4	1.0	2.3	1.0	0.8	2.3
Prolonged ventilation	8.9	6.1	14.3	6.1	4.5	13.5
Atrial fibrillation, postoperative	24.1	23.6	25.1	26.0	25.3	29.1
Postprocedure length of stay, days	6 (5–8)	6 (4–7)	7 (6–10)	6 (4–7)	5 (4–7)	7 (6–10)
Total ICU length of stay, hours	47 (24.8–78.3)	42.5 (24–70.7)	58.5 (29.5–110)	41 (24–69.8)	31.1 (23.5–58)	54.0 (28.7–99.5)
Readmission within 30 days	11.1	9.4	14.3	8.7	7.8	12.9
Unadjusted operative mortality	2.0	1.1	3.7	1.2	0.8	3.1

[a] Of the 1,800 patients with renal failure (2.1%), newly acquired dialysis was found in 1,131 (overall cohort), of whom 484 underwent repairs and 647 underwent replacement; within the DLP subgroup, of the 455 patients with renal failure (1.2%), newly acquired dialysis was found in 264 (overall cohort), of whom 155 underwent repairs and 109 underwent replacement. [b] $p = 0.9670$. [c] $p = 0.5303$. [d] $p = 0.0217$.

Values are percentage or median (interquartile range). All mean comparisons within each data grouping (overall and degenerative leaflet prolapse [DLP]) were significant ($p < 0.0001$) unless otherwise indicated.

ICU = intensive care unit; PPM = permanent pacemaker.

subgroup were associated with increasing center MV surgery volume (Table 7).

Comment

The implementation of substantially more detailed data elements pertaining to MV operations in the STS ACSD in 2011 has enabled a comprehensive report describing the contemporary state of MV surgery in North America.

The volume of isolated MV operations performed during the study period grew by 24%, and the subset of DLP operations grew by 44%. That is in comparison with an overall case volume growth of 11% in the STS ACSD. Mitral valve operations are the fastest growing surgical intervention captured in the STS ACSD [12]. Although the prevalence of MV disease is twofold to threefold higher in the community [13], overall AV operations (isolated and combined, exclusive of transcatheter aortic valve replacement) were performed 1.6 times more commonly than MV operations during the period studied. That may suggest important underreferral and undertreatment of MV disease, which may be related to the slower progression of signs and symptoms of mitral disease compared with aortic disease, as well as a potential lack of adherence to guidelines for intervention.

Patients referred for MV operations are relatively young and have low PROM score (overall 1.2%), a finding consistent with an earlier experience from the STS ACSD in which Chaterjee and colleagues [14] reported that 47% of isolated MV patients had a PROM less than 1%, and 82% had a PROM less than 4%. Although the overall preoperative risk profile in this experience was favorable, there was evidence that thresholds for optimal long-term outcomes were often exceeded. The mean preoperative ejection fraction was less than 60% in nearly half (47%) of the patients studied, the average sPAP was 40 mm Hg (9.6% had sPAP greater than 50 mm Hg), and one third of patients presented with AF.

It is clear that late referral for surgical intervention is associated with reduced survival [2, 15]. There remains an important and substantial opportunity to decrease long-term mortality in patients with MV disease by following established guidelines and encouraging earlier referral for operation.

The etiology of MV disease could be assessed in more than two thirds of patients. Among the 60,185 patients with an etiology identified, DLP was the most common cause of MV disease requiring operation (61%), followed by rheumatic disease (22%). Of interest, the number of patients undergoing operation with functional MR (ischemic and nonischemic) was very low, with functional MR identified as an etiology in fewer than 5% of patients. The low percentage of patients undergoing isolated MV operation for functional MR likely reflects the lack of data supporting either a survival benefit or symptom improvement for this intervention [16] and the current class IIb recommendation for intervention in the guidelines [17]. The ascertainment of etiology is probably

Table 7. Total Isolated Mitral Valve Surgery Volume for Patients With Degenerative Leaflet Prolapse

	Center Volume[a] (n = 1,020)				Case Volume[b] (n = 36,948)			
Total Isolated MV Surgery Volume	Centers n (%)	Avg Repair Rate (% [95% CI])	Avg O/E Ratio (95% CI)	Avg STS PROM Score (95% CI)	Cases (n)	Repair Rate (%)	Mortality (%)	STS Risk Score (Median [IQR])
≤23 cases per year	972 (95.3%)	66.9 (65.1–68.7)	1.03 (0.80–1.25)	1.97 (1.89–2.05)	21,987	75.9[c]	1.60[c]	0.94 (0.48–2.02)[c]
>23 cases per year	48 (4.7%)	90.0 (87.0–93.0)	0.50 (0.38–0.61)	1.38 (1.27–1.48)	14,961	92.2	0.61	0.64 (0.36–1.30)

[a] Repair rates, observed to expected (O/E) ratios, and The Society of Thoracic Surgeons (STS) risk scores were averaged across centers within respective volume category. [b] Repair rates, mortality, and STS risk scores were averaged across cases within respective volume category. [c] Mean comparisons between 22.75 or fewer cases per year and more than 22.75 cases per year within each column are significantly different ($p < 0.0001$) calculated by χ^2 and Wilcoxon-Mann-Whitney *U* test.

Surgical volume was divided into two groups at the 95th percentile of annual volume.

Avg = average; CI = confidence interval; IQR = interquartile range; MV = mitral valve; STS PROM = The Society of Thoracic Surgeons predicted risk of mortality.

imprecise, was not core laboratory adjudicated, and was clearly incomplete, and there is an opportunity for increased surgeon involvement in this determination. The percentage of patients with mitral stenosis (12%) was less than that of patients identified as having rheumatic disease, suggesting some imprecision in the determination of etiology.

The current analysis suggests that among patients with DLP, just over three quarters of those with severe MR undergoing operation present with symptoms, and that only approximately 10% are referred for operation without symptoms and with preserved ventricular function (class IIa). More than 1,000 patients per year with degenerative MR received a valve replacement as first-line surgical therapy, or left the operating room with moderate or severe residual MR after attempted mitral repair. There was wide variability in risk-adjusted operative mortality, repair rates, and repair quality. Most centers operated on 3 or fewer patients with degenerative MR annually, and degenerative repair rates averaged only 56% at the lowest volume centers. Significant improvements in operative mortality and repair rates were observed with increasing surgical volume. In this patient population, this finding may define an opportunity to improve repair rates through referral to more experienced MV repair centers and surgeons [18, 19].

Although sternotomy remains the dominant surgical approach for isolated MV operations, nearly one quarter of operations in this experience were performed using less invasive nonsternotomy approaches. A previous report from the ACSD described an increase in the frequency of less invasive operations from 12% in 2004 to 20% in 2008 [20]. Robotic-assisted approaches are now used in 12% of all patients with DLP. Although there has been a small increase in the percentage of cases performed in a less invasive manner, there may be a plateau in enthusiasm for these approaches.

Concomitant tricuspid repair was performed in nearly 16% of patients, a stable rate compared with previous reports [4]. Among patients with AF, only half had a concomitant AF ablation procedure performed at the time of MV operation. Recently published STS clinical practice guidelines for the surgical treatment of AF have a class 1 recommendation supported by level A evidence to perform concomitant AF ablation to restore sinus rhythm during MV operations when AF is present [21, 22], and implementation of this recommendation is an important means of improving care of patients with MV disease—and is an important potential quality metric.

Mitral valve repair rates for the overall cohort declined between 2011 and 2016, and were 63% for the most recent year studied (2016). This repair rate is similar to the 61% reported for 2007 in a prior STS ACSD publication [4]. For patients with DLP, the repair rates were stable between 2011 and 2016 and approximated 80%. Unadjusted outcomes for replacement compared with repair demonstrated a consistent twofold to threefold higher operative mortality. Unadjusted morbidities including stroke and renal failure were substantially higher in the repair group compared with replacement group, and the rate of permanent pacemaker implantation in the DLP group was threefold higher (10.5% versus 3.1%) in the replacement group.

This analysis reports for the first time the rate of attempted but unsuccessful repairs among patients receiving MV replacements. In 16% of cases, the surgeon attempted a repair before replacing the valve, and the rate of attempted but unsuccessful repair was 27% among patients with DLP who ultimately underwent replacement. These findings suggest that significant opportunities exist to help surgeons identify which patients can undergo repair and to assist them in carrying out successful repairs. The 82.5% repair rate for DLP is substantially lower than reports from single-center series, where nearly 100% of degenerative MV patients undergo repairs [23, 24]. This discrepancy may arise in part from incomplete documentation of etiology in the STS database, but likely predominantly represents an opportunity to improve repair rates in North America. The American College of Cardiology/American Heart Association guidelines classify MV replacement for isolated posterior leaflet prolapse limited to less than half of the posterior leaflet as a class III (harm recommendation) [17]. Our center volume analysis confirms other studies suggesting that one mechanism to improve repair rates is to encourage referral to reference centers and surgeons [19]. Other possibilities to improve repair rates include new technologies to facilitate higher rates and quality of MV repair [24], better training, and triage of high-complexity degenerative cases [25–27].

As has been reported for surgical AV replacement [28, 29], a steady increase in percentages of MV replacement patients with bioprosthetic compared with mechanical valves was observed in this study. In the most recent year of this analysis, three quarters of patients having MV replacement received tissue valves (porcine more commonly than bovine pericardial), demonstrating a trend toward bioprosthetic valve choice for MV replacement. In 2007, 63% of MV replacements were bioprosthetic [4]. Probable reasons for this shift may include patient preference to avoid anticoagulation therapy, and for the patient with high comorbidities, surgeon awareness of a future potential transcatheter valve-in-valve reintervention options [30].

Operative techniques for MV repair included near universal use of annuloplasty devices, the majority of which were rings compared with bands. Although leaflet resection remains the most common approach to MV repair among patients with degenerative leaflet prolapse, nearly one quarter of patients had nonresectional artificial expanded polytetrafluoroethylene cordal repairs. It was of interest that a median of only two pairs of expanded polytetrafluoroethylene cords were used for repair, and future efforts to identify repair failure predictors might include the number of cords used [31].

One third of patients had a predismissal transthoracic echocardiography performed. The rate of moderate or severe MR at discharge for patients with DLP was 3.2% and was similar to that seen in the operating room at the end of bypass. Routine intraoperative and predischarge echocardiography represent potential process quality metrics for assessing MV programs and a route for improving clinical outcomes. This type of public reporting has been associated with substantial improvements in practice and outcomes for coronary artery bypass surgery, and although the relatively small number of mitral operations at most centers may preclude meaningful reporting of surgeon-specific outcome data for degenerative mitral repair, there is clearly scope to drive much needed practice improvements that may contribute to better patient outcomes.

As has been previously reported [18], we found that the large majority of MV operations are limited to a relatively small number of centers. Among centers performing MV surgery for patients with DLP, only 147 of 1,125 centers (13%) performed 10 or more isolated DLP MV operations per year. When centers were dichotomized at the 95th percentile, we found that repair rates in the high-volume centers (more than 22.75 cases per year) were significantly (16.4%) higher than those in lower volume centers; and although STS PROM scores were slightly higher in the lower volume centers, the average O/E mortality ratio and the unadjusted mortality rates were also higher in the lower volume centers.

Study Limitations

This report has the inherent limitations of any analysis of a large registry. One key limitation is incomplete data, particularly that related to etiology. Because etiology is entered by data managers rather than coming directly from surgeons, it is possible that assignments were incorrect or incomplete. It is also possible that surgeon assessment of valve etiology was incorrect or biased by operative outcomes. All echocardiographic data were site-reported and not core laboratory adjudicated. In addition, predicted risk was based on established variables in the STS risk model for MV operations, and these do not include the performance of tricuspid valve repair or AF ablation.

In conclusion, isolated MV operations in North America are performed with very low rates of morbidity and mortality. Mitral valve repair is the fastest growing category of surgical intervention captured in the STS ACSD. At presentation, the majority of patients with MV DLP have symptoms or ventricular dysfunction, and few are currently referred for class IIa indications. We observed wide variability in the safety and quality of surgery in patients with degenerative MV disease. Degenerative MV repair rates were just over 50% at the lowest volume centers, and significant improvements were associated with increasing institutional case volume. Our data support concentrating surgeon experience in MV surgery, particularly for patients for whom the benefit of early surgery is entirely contingent on a safe and successful MV repair. There is growing use of bioprosthetic MVs among patients requiring replacement, and the use of less invasive operative approaches appears to have plateaued. Although contemporary outcomes are excellent, earlier guideline-directed referral and increased frequency and quality of repair may further enhance quality of MV operations.

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References

1. Suri RM, Vanoverschelde J-L, Grigioni F, et al. Association between early surgical intervention versus watchful waiting and outcomes for mitral regurgitation due to flail mitral valve leaflets. JAMA 2013;310:609–16.
2. Enriquez-Sarano M, Suri RM, Clavel M-A, et al. Is there an outcome penalty linked to guideline-based indications for valvular surgery? Early and long-term analysis of patients with organic mitral regurgitation. J Thorac Cardiovasc Surg 2015;150:50–8.
3. Lazam S, Vanoverschelde JL, Tribouilloy C, et al. Twenty-year outcome after mitral repair versus replacement for severe degenerative mitral regurgitation: analysis of a large, prospective, multicenter, international registry. Circulation 2017;135:410–22.
4. Gammie JS, Sheng S, Griffith BP, et al. Trends in mitral valve surgery in the United States: results from The Society of Thoracic Surgeons Adult Cardiac Surgery Database. Ann Thorac Surg 2009;87:1431–7.
5. The Society of Thoracic Surgeons National Database. Available at http://www.sts.org/national-database. Accessed August 29, 2017.
6. Winkley Shroyer AL, Bakaeen F, Shahian DM, et al. The Society of Thoracic Surgeons Adult Cardiac Surgery Database: the driving force for improvement in cardiac surgery. Semin Thorac Cardiovasc Surg 2015;27:144–51.
7. Rankin JS, Grau-Sepulveda M, Shahian DM, et al. The impact of mitral disease etiology on operative mortality after mitral valve operations. Ann Thorac Surg 2018; May 17 [in press accepted manuscript].
8. Adult Cardiac Surgery Data Collection. Available at http://www.sts.org/sts-national-database/database-managers/adult-cardiac-surgery-database/data-collection. Accessed August 29, 2017.
9. Zoghbi WA, Chambers JB, Dumesnil JG, et al. Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report From the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves. J Am Soc Echocardiogr 2009;22:975–1014.
10. O'Brien SM, Shahian DM, Filardo G, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: part 2—isolated valve surgery. Ann Thorac Surg 2009;88(Suppl):23–42.
11. Nishimura RA, Otto CM, Bonow RO, et al. American College of Cardiology/American Heart Association Task Force on Practice Guidelines. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol 2014;63:2438–88.
12. D'Augustino RS, Jacobs JP, Badhwar V, et al. The Society of Thoracic Surgeons Adult Cardiac Surgery Database: 2017 update on outcomes and quality. Ann Thorac Surg 2017;103:18–24.
13. Nkomo VT, Gardin JM, Skelton TN, Gottdiener JS, Scott CG, Enriquez-Sarano M. Burden of valvular heart diseases: a population-based study. Lancet 2006;368:1005–11.
14. Chatterjee S, Rankin JS, Gammie JS, et al. Isolated mitral valve surgery risk in 77,836 patients from The Society of Thoracic Surgeons database. Ann Thorac Surg 2013;96:1587–95.
15. Ghoreishi M, Evans CF, DeFilippi CR, et al. Pulmonary hypertension adversely affects short- and long-term survival after mitral valve operation for mitral regurgitation: implications for timing of surgery. J Thorac Cardiovasc Surg 2011;142:1439–52.
16. Wu AH, Aaronson KD, Bolling SF, Pagani FD, Welch K, Koelling TM. Impact of mitral valve annuloplasty on mortality risk in patients with mitral regurgitation and left ventricular systolic dysfunction. J Am Coll Cardiol 2005;45:381–7.
17. Nishimura RA, Otto CM, Bonow RO, et al. 2017 AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol 2017;70:252–89.
18. Chikwe J, Toyoda N, Anyanwu AC, et al. Relation of mitral valve surgery volume to repair rate, durability, and survival. J Am Coll Cardiol 2017 April 24 [E-Pub ahead of print].
19. Gillinov AM, Mick S, Suri RM. The specialty of mitral valve repair. J Am Coll Cardiol 2017;69:2407–9.
20. Gammie JS, Zhao Y, Peterson ED, O'Brien SM, Rankin JS, Griffith BP. Less-invasive mitral valve operations: trends and outcomes from The Society of Thoracic Surgeons Adult Cardiac Database. Ann Thorac Surg 2010;90:1401–10.
21. Gammie JS, Haddad M, Milford-Beland S, et al. Atrial fibrillation correction surgery: lessons from The Society of Thoracic Surgeons National Cardiac Database. Ann Thorac Surg 2008;85:909–15.
22. Badhwar V, Rankin JS, Damiano RJ, et al. The Society of Thoracic Surgeons 2017 clinical practice guidelines for the surgical treatment of atrial fibrillation. Ann Thorac Surg 2017;103:329–41.
23. Castillo JG, Anyanwu AC, Fuster V, Adams DH. A near 100% repair rate for mitral valve prolapse is achievable in a reference center: implications for future guidelines. J Thorac Cardiovasc Surg 2012;144:308–12.
24. Gammie JS, Bartlett ST, Griffith BP. Small-incision mitral valve repair: safe, durable, and approaching perfection. Ann Surg 2009;250:409–15.
25. Anyanwu AC, Adams DH. Why do mitral valve repairs fail? J Am Soc Echocardiogr 2009;22:1265–8.
26. Anyanwu AC, Bridgewater B, Adams DH. The lottery of mitral valve repair surgery. Heart 2010;96:1964–7.
27. Adams DH, Rosenhek R, Falk V. Degenerative mitral valve regurgitation: best practice revolution. Eur Heart J 2010;31:1958–67.
28. Brown JM, O'Brien SM, Wu C, Sikora JA, Griffith BP, Gammie JS. Isolated aortic valve replacement in North America comprising 108,687 patients in 10 years: changes in risks, valve types, and outcomes in The Society of Thoracic Surgeons National Database. J Thorac Cardiovasc Surg 2009;137:82–90.
29. Thourani VH, Suri RM, Gunter RL, et al. Contemporary real-world outcomes of surgical aortic valve replacement in 141,905 low-risk, intermediate-risk, and high-risk patients. Ann Thorac Surg 2015;99:55–61.
30. Condado JF, Kaebnick B, Babaliaros V. Transcatheter mitral valve-in-valve therapy. Interv Cardiol Clin 2016;5:117–23.
31. Gammie JS, Wilson P, Bartus K, et al. Transapical beating-heart mitral valve repair with an expanded polytetrafluoroethylene cordal implantation device: initial clinical experience. Circulation 2016;134:189–97.