Outcomes after mitral valve repair: A single-center 16-year experience

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ABSTRACT

Objective: To evaluate outcomes after mitral valve repair.

Methods: Between May 1999 and June 2015, 446 patients underwent mitral valve repair. Isolated mitral valve annuloplasty was excluded. A total of 398 (89%) had degenerative valve disease. Mean follow-up was 5.5 ± 3.8 years. Postoperative echocardiograms were obtained in 334 patients (75%) at a mean of 24.3 ± 13.7 months.

Results: Survival was 97%, 96%, 95%, and 94% at 1, 3, 5, and 10 years. Risk factor analysis showed age >60 years and nondegenerative etiology predict death (hazard ratio, 2.91; 95% confidence interval, 1.06-8.02, $P = .038$; and hazard ratio, 1.87; 95% confidence interval, 1.16-3.02, $P = .010$, respectively). Considering competing risks due to mortality, the cumulative incidence of reoperation was 2.8%, 4.2%, 5.1%, and 9.6% at 1, 3, 5, and 10 years. Competing risk proportional hazard survival regression identified nondegenerative etiology and previous cardiac surgery as predictors of reoperation, and posterior repair was protective (all $P < .05$). Cumulative incidence of progression of mitral regurgitation (2 or more grades) with mortality as a competing risk was 4.7%, 10.5%, 21.0%, and 35.8% at 1, 3, 5, and 10 years. Patients with previous sternotomy, repair or coronary artery bypass grafting, and concurrent tricuspid valve procedure or isolated anterior leaflet repair were more likely to develop progression of mitral regurgitation (all $P < .05$), and posterior leaflet repair was protective ($P = .038$). On multivariate analysis diabetes, previous coronary artery bypass grafting and concurrent tricuspid valve intervention predicted MR progression.

Conclusions: Mitral valve repair has excellent outcomes. Our results demonstrate failures appear to occur less in those who undergo posterior leaflet repair. (J Thorac Cardiovasc Surg 2017;154:822-30)

Cumulative incidence of progression of mitral regurgitation by posterior leaflet repair.

Central Message

Mitral valve repair is associated with excellent survival, reoperation rates, and durability, especially in those undergoing posterior leaflet repairs.

Perspective

Recurrence of mitral regurgitation after mitral valve repair is associated with increased morbidity and mortality. Current outcomes with mitral valve repair are excellent particularly in those who require posterior leaflet repairs. We should consider these surgical results in an era of potential increased application of percutaneous mitral valve therapy.

See Editorial Commentary page 831.

Mitral valve repair is accepted widely to improve survival and quality of life.^{1,2} Rates of reoperation and the progression of mitral regurgitation (MR) after mitral valve repair vary widely. In addition, numerous studies demonstrate a persistent failure rate after repair inherently

related to the inability of surgery to correct the underlying disease process.³⁻¹⁶ The Brigham and Women's Hospital group reported a 20-year incidence of mitral reoperation of 18%, whereas the Toronto group reported a reoperation rate of only 5.9%.⁶ Recurrence of moderate-to-severe MR

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Abbreviations and Acronyms

CI	= confidence interval
HR	= hazard ratio
MR	= mitral regurgitation
SHR	= subhazard ratio
TTE	= transthoracic echocardiography
USC	= University of Southern California

Scanning this QR code will take you to a procedural video, supplemental figure, and tables for this article.

at 20 years in the latter study was 30.8%, whereas the Mayo clinic group recently reported a 15-year incidence of significant recurrent MR of 13.3%.⁶⁻⁸ Risk factors for the recurrence of MR after mitral valve repair vary greatly but most consistently include factors such as presence of anterior or bileaflet pathology, absence of posterior leaflet pathology, lack of an annuloplasty ring, and longer cardiopulmonary bypass times.⁶⁻⁹

We sought to examine outcomes of mitral valve repair and analyze risk factors for death, reoperation, and progression of MR. An analysis of this nature is especially timely, given the increasing adoption of percutaneous mitral valve repair and replacement technology.

MATERIALS AND METHODS

This study was conducted in accordance to the “Guidelines for reporting mortality and morbidity after cardiac valve interventions.”¹⁷ This was a systematic retrospective cohort study of consecutive patients undergoing mitral valve repair at the University of Southern California (USC; formerly USC University Hospital, now Keck Hospital of USC) between May 1999 and July 2015. The follow-up period closed July 2016. Mitral valve repair was defined as mitral valve reconstruction with or without an annuloplasty ring. Patients who underwent isolated mitral valve annuloplasty for the treatment of MR were excluded. Patients undergoing other concomitant cardiac procedures were included. The institutional review board of the University of Southern California Health Sciences Campus approved this study (HS-15-00509) and waived the requirement for patient consent. The senior author performed 85% of the procedures.

Patients, baseline demographics, operative characteristics, and perioperative outcomes were identified through the USC Cardiac Surgery Research Database and our Society of Thoracic Surgeons Adult Cardiac Database. Subsequent outcomes (follow-up transthoracic echocardiograms [TTEs], need for reoperation, and mortality) were collected actively and passively. All available medical records from our electronic medical record and the referring providers were reviewed. Recurrent MR was assessed from the report of an institutional or outside facility echocardiogram. Reoperation is defined as a repeat operation to the mitral valve, ie, second mitral valve repair or mitral valve replacement. No patient received a mitral valve clip or valve in band. Mortality was confirmed through direct patient, family, or provider contact; a search of local obituaries; and through access

VIDEO 1. Minimally invasive mitral valve repair of myxomatous disease. P2 is resected, folding valvuloplasty of P1 and P3 is performed, followed by reconstruction of the posterior leaflet. A neochord is placed to A1, which is secured after placement of a partial annuloplasty ring and distension of left ventricle to ensure proper neochordal height. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(17\)30185-X/addons](http://www.jtcvsonline.org/article/S0022-5223(17)30185-X/addons).

of the Social Security Death Index in collaboration with the University of California at San Francisco Clinical Translational Science Institute. Follow-up TTEs were not obtained at fixed time points but at the discretion of the physician.

The primary endpoints were mortality, need for mitral valve reoperation, and the progression of MR. MR was coded 0 to 4 based on echocardiogram reports (0 = none, 1 = trace, 2 = mild, 2.5 = mild-to-moderate, 3 = moderate, 3.5 = moderate-to-severe, 4 = severe). Progression of MR was defined as worsening of MR by more than 2 grades. As a secondary assessment, the incidence of grade 3.5 or 4 (moderate-to-severe or severe) MR over time was included.

Patients with partial follow-up were included; however, only patients with mortality data were included in the analysis of mitral reoperation or recurrence. Patients were censored from further recurrence analysis on the event of reoperation.

Surgical approach was either full sternotomy or minimally invasive right thoracotomy as per surgeon's preference. The mitral valve typically was accessed via the interatrial sulcus, although transseptal and left atrial dome approaches also were used. Peripheral cannulation was used for the minimally invasive approach. Posterior leaflet mitral valve repair generally involved resection of the diseased segment, annular plication, and reconstruction of the posterior leaflet (Video 1). The anterior leaflet was repaired by the placement of polytetrafluoroethylene neochordae (W. L. Gore & Associates, Inc, Flagstaff, Ariz) or resection and reconstruction. A true-sized, partial posterior mitral valve annuloplasty primarily was used.

Statistical Analysis

Preoperative and operative characteristics were summarized. For mortality, Cox proportional hazards regression was used to estimate and test associations of variables with time-to-event; Kaplan-Meier survival curves were used and comparisons between groups were made by log-rank tests. Statistical analysis of time to reoperation and MR recurrence considered mortality as a competing risk event. Nonparametric estimates of cumulative incidence (probability of reoperation or MR recurrence) were calculated.¹⁸ Survival regression used competing risks analysis with the Fine-Gray model¹⁹; results are presented as subhazard ratios (SHRs) and 95% confidence intervals (CIs). Characteristics that were associated with time-to-event at $P < .10$ on univariate analysis were selected for

TABLE 1. Preoperative and operative characteristics of entire cohort

	Entire cohort, N = 446
Preoperative characteristics	
Age, y	61 ± 13
Male	296 (66)
Nonwhite race	103 (23)
Body mass index, kg/m ²	26 ± 5
NYHA class*	2 (2, 3)
Diabetes	37 (8.3)
Atrial fibrillation	48 (10.8)
COPD	37 (8.3)
Previous myocardial infarction	23 (5.2)
Previous CVA	15 (3.4)
Renal failure	14 (3.1)
Ejection fraction, %	60 ± 10
Previous cardiac surgery	
Sternotomy	23 (5.2)
Previous mitral valve surgery	9 (2.0)
CABG	8 (1.8)
Any valve	15 (3.4)
Preoperative mitral valve assessment (echocardiogram)	
Leaflet involvement	
Anterior	58 (13.0)
Posterior	320 (71.7)
Anterior and posterior	52 (11.7)
Indeterminate	16 (3.6)
Preoperative MR grade	
0-2.5	25 (5.7)
3-3.5	62 (14.2)
4	351 (80.1)
Etiology	
Degenerative	398 (89.2)
Other	48 (10.8)
Operative characteristics	
Cardiopulmonary bypass time, min	93 ± 43
Cardiopulmonary bypass time >90 min	172 (39.5)
Crossclamp time, min	65 ± 35
Isolated mitral valve repair	306 (68.6)
Minimally invasive mitral valve repair	237 (53.1)
Concurrent procedure	
CABG	21 (4.7)
Aortic valve	24 (5.4)
Tricuspid valve	31 (7.0)
Aortic procedure	13 (2.9)
Ablation procedure	53 (11.9)
Septal myectomy	7 (1.6)
IABP	8 (1.8)
Ventricular assist device placement	1 (0.2)
Peripheral arterial cannulation	278 (62.3)
Need for second cardiopulmonary bypass	11 (2.5)
Minimally invasive incision	281 (63.0)
Type of mitral annuloplasty	
None	12 (2.7)
Partial	434 (97.3)
Complete	0

(Continued)

TABLE 1. Continued

	Entire cohort, N = 446
Size of mitral annuloplasty, mm	
26-29	104 (24.0)
30-31	117 (27.0)
32-34	169 (39.0)
36-38	43 (9.9)
Type of mitral valve repair	
Any posterior leaflet repair	377 (84.5)
Isolated posterior leaflet repair	314 (70.4)
Any anterior leaflet repair	132 (29.5)
Isolated anterior leaflet repair	69 (15.5)
Bileaflet repair	63 (14.1)

Continuous variables are expressed as mean ± standard deviation; categorical variables are expressed as frequency (percent). NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease; CVA, cerebral vascular accident; CABG, coronary artery bypass graft; MR, mitral regurgitation; IABP, intra-aortic balloon pump. *NYHA expressed as median (25th, 75th percentiles); group differences tested with Wilcoxon rank sum.

multivariate modeling. Final multivariate models for each outcome included characteristics that were significant at $P < .05$. Results are presented as hazard ratio (HR) and 95% CI. Data were collected with a Microsoft Excel spreadsheet (Microsoft Corp, Redmond, Wash) and further analyzed with STATA Version 14 (Statistical Software, College Station, Tex).

RESULTS

Characteristics of Overall Cohort

A total of 1754 mitral valve procedures were performed during this time period, of which 810 (46%) were mitral valve repairs and 944 (54%) were mitral valve replacements. Of the repairs, 446 involved mitral valve repair with or without mitral valve annuloplasty and met inclusion criteria (25% of all mitral valve procedures and 55% of all mitral valve repairs, see Table E1). A Consolidated Standards of Reporting Trials type diagram is included in Figure E1. Preoperative and operative characteristics are shown in Table 1. The cohort was relatively young (61 ± 13 years) with few comorbidities and moderate-to-severe or severe MR with mild-to-moderate symptoms. Most (89%) had degenerative disease, and 34% were female.

The posterior leaflet was most repaired commonly (84%) and, of these, 83% were isolated posterior leaflet repairs. One third had an anterior leaflet repair and, of these, one half were isolated anterior leaflet repairs.

More than one half of patients underwent a minimally invasive approach (63%). Of the 69% who underwent isolated mitral valve repair, 77% had a minimally invasive approach. Minimally invasive thoracotomy was converted to full sternotomy in one case (<1%). For the sternotomy group, average cardiopulmonary and crossclamp times were 112 and 81 minutes, respectively, whereas these times

FIGURE 1. Kaplan-Meier survival for entire cohort.

were 82 and 55 minutes, respectively, in the minimally invasive group. This difference reflects the greater number of concomitant procedures via sternotomy (data not shown).

Intraoperative transesophageal echocardiography results were available in 93.3% of patients. Ninety-nine percent of patients left the operating room with less than grade 2 MR, and none left the operating room with more than grade 2.5 MR. Intraoperative transesophageal echocardiography revealed persistent MR secondary to systolic anterior motion in 9 (2%) patients, all of which were successfully repaired on second attempt.

There were concurrent cardiac surgery procedures in 145 (33%) patients, most commonly an ablation procedure for atrial fibrillation (33.5% of concurrent procedures). Of

the 31 patients who had concomitant tricuspid valve surgery, all had moderate-to-severe or severe tricuspid regurgitation preoperatively. Of these, 27 underwent tricuspid valve annuloplasty while the remainder had primary repair, a DeVega procedure, or replacement. Average tricuspid annuloplasty ring size was 34 ± 2.1 mm.

Survival

Follow-up data for mortality were available in all patients at a mean of 5.5 ± 3.8 years (range 0-15.8 years). Mortality occurred in 20 patients during the study period. Thirty-day mortality was 0.9%. Kaplan-Meier survival was 97%, 96%, 95%, and 94% at 1, 3, 5, and 10 years (Figure 1, CIs reported in Table E2). Risk factor analysis for mortality is shown in Table 2. Age >60 years and nondegenerative etiology were predictive of death (HR, 2.91; 95% CI, 1.06-8.02, $P = .038$; and HR, 1.87; 95% CI, 1.16-3.02, $P = .010$, respectively).

Need for Mitral Valve Reoperation

Follow-up data for mitral valve reoperation were available in 364 patients (82%) at a mean of 5.3 ± 3.7 years (range 0-15.4 years). Characteristics of those with and without reoperative data available for analysis are shown in Table E3. Reoperation was required in 24 patients. Considering competing risks due to mortality, the cumulative incidence of mitral valve reoperation was 2.8%, 4.2%, 5.1%, and 9.6% at 1, 3, 5, and 10 years. Competing risk proportional hazard survival regression incorporating mortality as a competing risk identified nondegenerative etiology and previous cardiac surgery as predictors of reoperation, whereas any posterior repair was protective

TABLE 2. Risk factor analysis of mortality and reoperation

Variable	Mortality (n = 20)						Reoperation (n = 24)			
	Overall (N = 446)		Cox proportional hazard regression*				Competing risk proportional hazard regression*			
			Yes	No	HR (95% CI)	P value†	Yes	No	SHR (95% CI)	P value*
Sex (male)	296	11	285		0.56 (0.23-1.36)	.201	17	222	1.23 (0.52-2.90)	
Age, y	61 ± 13	67 ± 14	60 ± 13				60 ± 14	61 ± 13		
Age >60 y, n	231	15	216		2.91 (1.06-8.02)	.038	12	174	1.00 (0.45-2.20)	1.00
Nondegenerative etiology, n	48	6	42		1.87 (1.16-3.02)	.010	9	39	2.39 (1.57-3.64)	<.001
Previous cardiac surgery, n	23	2	21		1.84 (0.43-7.94)	.414	4	12	4.18 (1.55-11.3)	.005
Concurrent surgery, n	145	9	136		1.67 (0.69-4.03)	.255	11	108	1.76 (0.81-3.83)	.16
Concurrent TV surgery, n	31	3	28		2.61 (0.76-8.93)	.127	2	25	1.54 (0.40-5.94)	.53
Any anterior repair, n	132	8	124		1.57 (0.64-3.84)	.323	11	97	1.89 (0.86-4.16)	.12
Any posterior repair, n	377	16	361		0.76 (0.25-2.28)	.626	15	291	0.34 (0.15-0.75)	.007
Cardiopulmonary bypass, min	93 ± 43	110 ± 57	92 ± 42				98 ± 40	93 ± 43		
>90 min, n	183	10	173		1.44 (0.60-3.46)	.416	10	125	1.22 (0.54-2.74)	.63
Crossclamp time	65 ± 35	76 ± 38	64 ± 34				62 ± 32	65 ± 35		
>60 min, n	183	12	171		2.30 (0.94-5.64)	.068	7	129	0.75 (0.31-1.81)	.53

HR, Hazard ratio; CI, confidence interval; SHR, subhazard ratio; TV, tricuspid valve. *P values from Cox or competing risks regression are univariate. †Continuous variables are expressed as mean ± standard deviation; categorical variables are expressed as frequency.

FIGURE 2. Nonparametric estimates of cumulative incidence of the probability of reoperation with death as a competing outcome for presence (dashed line) or absence (solid line) of any posterior leaflet repair. Table E2 for confidence intervals.

(all $P < .05$). Concomitant surgery was of borderline increased risk ($P = .076$) (Table 2). Nonparametric estimates of cumulative incidence of the probability of reoperation based on the presence or absence of a posterior leaflet repair (with mortality as a competing outcome) are shown in Figure 2 (CIs reported in Table E2).

Progression of MR

Follow-up data for progression of MR were available in 334 patients (75%) at a mean of 2.0 ± 1.1 years (range 0-15.2 years). Characteristics of those with and without progression of MR data available for analysis is shown in Table E4. In the 17 patients with follow-up who left the operating room with either grade 2 or 2.5 MR, no patient developed progression to grade 4 MR.

MR progression of 2 or more grades occurred in 31 patients. When we considered competing risks due to mortality, the cumulative incidence of MR progression of 2 or more grades was 4.7%, 10.5%, 21.0%, and 35.8% at 1, 3, 5, and 10 years. Competing risk proportional hazard regression for recurrence of MR with mortality as a competing event is shown in Table 3. Patients with a previous sternotomy, previous mitral valve or coronary artery bypass grafting surgery, concurrent tricuspid valve procedure, or isolated anterior leaflet repair were more likely to develop progression of MR (all $P < .05$). Lower ejection fraction and advanced age were of borderline increased risk ($P = .06$ and $.09$, respectively). Any posterior leaflet repair was protective from progression of MR ($P = .038$). Nonparametric estimates of cumulative incidence of the recurrence of MR greater than 2 grades based on the presence or absence of a posterior leaflet repair (with death as a competing outcome) are shown in Figure 3 (CIs reported in Table E2).

When we used the secondary assessment of those with moderate-to-severe or severe MR (grade 3.5 or 4), the Kaplan-Meier freedom from recurrence improved to

99%, 96%, 93%, and 74% at 1, 3, 5, and 10 years (this analysis did not account for death as a competing outcome).

The strong trend of posterior leaflet repair as a protector from MR progression over time also was demonstrated on multivariate analysis with mortality as a competing risk (SHR, 0.50; CI, 0.21-1.15, $P = .10$, Figure 4). In addition, diabetes, previous coronary artery bypass grafting, and concurrent tricuspid valve intervention remained predictors of progression of MR.

To analyze this further, we examined the 257 patients who underwent isolated resection of the posterior leaflet, segment 2. Follow-up TTE was available in 191 of these patients (74%). Kaplan-Meier freedom from progression of MR by more than 2 grades was 97%, 92%, and 77% at 1, 3, and 5 years. Although the HR was less than 1, this difference did not reach statistical significance (0.46; 95% CI, 0.21-0.74, $P = .12$).

DISCUSSION

This study analyzed outcomes after mitral valve repair. The key findings are that survival after mitral valve repair is excellent and need for reoperation is uncommon. In addition, there is a small but inherent failure risk over time, which appears less prominent with posterior leaflet repair.

Overall survival was excellent. Perioperative mortality was less than 1%, and 10-year survival was 94%. These results are comparable with other series of mitral valve repair for predominantly degenerative disease. The Mount Sinai group reported a 0.8% in-hospital mortality and 1- and 5-year survival of 99 and 97%, whereas the Brigham and Women's Hospital group reported a 30-day mortality of 0.6% and 10-year survival of 79%.^{7,9} Risk factors for death included a nondegenerative etiology and age >60 years. Others have identified increasing age, New York Heart Association functional class, smoking history, coronary artery disease, chronic obstructive pulmonary disease, left ventricular ejection fraction, lack of annuloplasty ring, and recurrent MR as risk factors for mortality.^{6,8}

Need for mitral valve reoperation was uncommon in our cohort, with a cumulative incidence of 9.6% at 10 years, when we took death into consideration as a competing risk. Reoperation was slightly more common in our cohort than in other large series. Freedom from reoperation of 97% at 7 years, 90% to 96% at 10 years, and 93% at 15 years have been reported recently by various centers, although whether or not death was considered as a competing risk in these series is unclear.⁶⁻⁹ The absence of a posterior repair was correlated strongly with need for mitral reoperation in our series, although part of this effect is likely due to the 10% of patients with etiologies of nondegenerative nature.

Differences and challenges in follow-up make direct comparisons of recurrence rates difficult. The Mayo Clinic

TABLE 3. Competing risk proportional hazard regression for recurrence of MR (mortality competing event)

Variable	MR recurrence (≥2 grades)	
	SHR (95% CI)	P value
Preoperative characteristics		
Age (per 10 y)	1.24 (0.97-1.58)	.09
Male	0.68 (0.33-1.36)	.27
Nonwhite race	0.94 (0.36-2.43)	.90
Body mass index, kg/m ²	1.02 (0.98-1.07)	.29
NYHA class	1.08 (0.63-1.86)	.77
Diabetes	2.43 (0.89-6.65)	.08
Atrial fibrillation	1.24 (0.43-3.51)	.69
COPD	1.65 (0.63-4.31)	.31
Previous myocardial Infarction	1.06 (0.13-8.50)	.96
Previous CVA	1.15 (0.18-7.30)	.88
Renal failure	—*	
Ejection fraction, %	0.97 (0.95-1.00)	.06
Previous cardiac surgery		
Sternotomy	3.97 (1.51-10.45)	.005
Mitral valve	4.33 (1.60-11.72)	.004
CABG	16.89 (3.97-71.82)	<.001
Any valve	1.63 (0.44-5.98)	.47
Preoperative mitral valve assessment		
Leaflet involvement		
Anterior	1.00	
Posterior	0.72 (0.30-1.75)	.47
Anterior and posterior	0.51 (0.12-2.13)	.35
Annulus	—*	
Preoperative MR grade		
1-2.5	1.00	
3-3.5	0.64 (0.12-3.49)	.61
4	0.81 (0.19-3.45)	.78
Operative characteristics		
Cardiopulmonary bypass time, min	1.00 (0.99-1.01)	.98
Cardiopulmonary bypass time >90 min	1.02 (0.51-2.06)	.95
Crossclamp time	1.00 (0.99-1.01)	.55
Isolated mitral valve repair	0.69 (0.34-1.43)	.32
Minimally invasive	0.75 (0.36-1.55)	.43
Concurrent procedure		
CABG	1.03 (0.21-5.11)	.97
Aortic valve	0.90 (0.22-3.62)	.88
Tricuspid valve	4.10 (1.59-10.58)	.004
Aortic procedure	—*	
Ablation procedure	1.78 (0.80-3.97)	.16
Septal myectomy	2.73 (0.33-22.29)	.35
IABP	4.49 (0.53-38.06)	.17
Ventricular assist device placement	—*	
Peripheral arterial cannulation	1.41 (0.68-2.92)	.36
Need for second cardiopulmonary bypass	—*	
Minimally invasive incision	1.31 (0.61-2.78)	.49
Type of mitral annuloplasty		
None	1.00	
Partial	—*	
Complete		

(Continued)

TABLE 3. Continued

Variable	MR recurrence (≥2 grades)	
	SHR (95% CI)	P value
Size of mitral annuloplasty, mm		
26-29	1.00	
30-31	1.37 (0.55-3.38)	.50
32-34	1.23 (0.52-2.91)	.64
36-48	1.02 (0.22-4.85)	.98
Type of mitral valve repair		
Any posterior repair	0.44 (0.20-0.96)	.038
Isolated posterior repair	0.56 (0.27-1.16)	.12
Any anterior repair	1.79 (0.86-3.71)	.12
Isolated anterior repair	2.26 (1.05-4.89)	.038
Bileaflet intervention	0.99 (0.35-2.80)	.99

MR, Mitral regurgitation; SHR, subhazard ratio; CI, confidence interval; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease; CVA, cerebral vascular accident; CABG, coronary artery bypass graft; IABP, intra-aortic balloon pump. *Model did not converge.

group recently published a report of 1218 patients undergoing mitral valve repair for degenerative mitral valve disease with a follow-up of 11 ± 4.5 years. The 15-year incidence of recurrence of moderate or severe MR was 13.3%.⁸ David and colleagues⁶ also recently reported a series of 840 patients with freedom from moderate-to-severe or severe MR of 96 and 90% at 10 years and 91 and 69% at 20 years.

We chose a rather stringent definition of progression of MR as an increase of more than 2 grades, and we also included death as a competing outcome. This definition could overestimate the incidence of clinically relevant recurrent MR. For instance, a patient progressing from no MR (ie, grade 0) to mild-to-moderate MR (ie, grade 2.5) is considered a failure. Therefore, we included a secondary potentially more meaningful clinical endpoint of postoperative MR progression to moderate-to-severe (grade 3.5) or severe (grade 4). When we used our more stringent definition of progression more than 2 grades with death as a competing outcome, the cumulative incidence of progressive MR at 5 and 10 years was 21.0% and 35.8%. This number decreases to 7% and 26% at 5 and 10 years if one considers just those patients with moderate-to-severe or severe MR.

Predicting who will develop recurrent MR after mitral valve repair remains problematic. Mitral valve repair, unfortunately, does not cure the underlying disease, and disease progression often is implicated in those who fail. In our study, risk factors on multivariate analysis for progression of MR considering death as a competing risk were diabetes, previous coronary artery bypass grafting, and concurrent tricuspid valve repair. The presence of a posterior leaflet repair was protective from progression by

FIGURE 3. Nonparametric estimates of cumulative incidence of the probability of progression of mitral regurgitation more than 2 grades with death as a competing outcome for presence (*dashed line*) or absence (*solid line*) of any posterior leaflet repair. See [Table E2](#) for confidence intervals.

univariate analysis ($P = .038$) and of borderline clinical significant on multivariate analysis (SHR, 0.10; $P = .10$). Those with an isolated anterior leaflet repair were more likely to recur on univariate analysis (SHR, 2.26; $P = .038$).

Our results are similar to those of others who have found a multitude of factors associated with recurrent MR after mitral valve repair for primarily degenerative disease. Suri and colleagues⁸ found multiple predictive factors for recurrence, including age, mild intraoperative residual regurgitation, anterior leaflet prolapse, bileaflet prolapse, perfusion time, and lack of annuloplasty. David and colleagues⁶ found that age, isolated prolapse of the anterior leaflet, degree of myxomatous change, lack of mitral annuloplasty, and duration of cardiopulmonary bypass were associated with an increased risk of recurrence. Again, unlike our study, it is unclear which, if any, previous studies accounted for death as a competing risk in these analyses.

These data and our own support the concept that progression of MR after mitral valve repair is less with posterior leaflet pathology repairs and greater with anterior or bileaflet disease and/or repairs. To further analyze this, we

looked at freedom from progression of MR in the subgroup of patients that had isolated posterior leaflet, segment 2 resections. Although not statistically protective from MR progression, freedom from recurrence at 5 years was greater than the overall group (83 vs 79%). The other factors we identified, including diabetes, previous coronary artery bypass grafting, and concurrent tricuspid valve repair, are difficult to interpret and are likely related to selection of patients with more advanced disease.

Meticulous surgical technique is clearly a component to a durable repair. Our repair strategies have evolved but include several important principles. First, we prefer the simplest possible repairs, especially in elderly patients. Second, posterior repair typically includes a resection and annular plication of the posterior annulus, which decreases posterior leaflet height and increases tension on the remaining chordae. We also have decreased our use of neochordae in favor of more anterior resections, because these anecdotally seem more durable. Although others may advocate leaving anterior mitral valve pathology untreated, our preference is for repair.²⁰ Last, we almost always place a true-sized posterior annular ring and were early adopters of this technique.

This analysis of outcomes after mitral valve repair is especially timely given the recent approval of the MitraClip (Abbott Vascular, Menlo Park, Calif) for severely symptomatic patients with severe MR who are not surgical candidates.^{2,21} The MitraClip mimics the surgical edge-to-edge repair. The EVEREST (Endovascular Valve Edge-to-Edge REpair STudy) II trial randomized 279 patients with moderately severe or severe MR to percutaneous repair with the MitraClip or conventional repair.²² These patients were not considered high surgical risk and had a mean age of 67 years, which is very similar to our cohort of patients. At 4 years, percutaneous repair was associated with similar mortality and symptomatic improvement but a greater rate of MR requiring repeat surgery.^{21,22} The initial commercial experience with transcatheter mitral repair in the United States recently was reported in which 456

FIGURE 4. Forest plot of variables associated with MR progression more than 2 grades after multivariate adjustment. *Solid point* represents hazard ratio. Bars represent 95% CIs. MR, Mitral regurgitation; CABG, coronary artery bypass grafting; SHR, subhazard ratio; CI, confidence interval.

patients with a median age of 83 years underwent MitraClip placement.²³ Median Society of Thoracic Surgery 30-Day Predicted Risk of Mortality scores were high (7.9%-10.0%). Procedural success and reduction of MR was achieved in 91% of patients, suggesting that this treatment is effective in a commercial setting in selected patients at high risk for surgical intervention.²³

The recommendations and approval currently limit this technology to patients of prohibitive operative risk.^{24,25} As the MitraClip evolves and other repair and replacement technologies enter clinical trials in an attempt to prove noninferiority (or superiority) to surgical techniques and applicability to lower risk patients, it is important that we consider the excellent outcomes with surgical mitral valve repair. Every surgeon will have to assess whether they truly have equipoise and whether it is ethical to enroll what would have otherwise been an appropriate surgical candidate for mitral valve repair in one of these trials, particularly those with posterior leaflet disease.

This study has numerous limitations. This was a retrospective cohort study from a single center and has the inherent limitations of this type of analysis. Although our attempts to obtain complete follow-up were exhaustive, we unfortunately did not obtain routine TTE at prespecified times, and follow-up studies were not available for 25% of patients. We largely relied on outside TTE reports, which made controlling for consistency and adjudication impossible. It is possible we have overestimated the longitudinal recurrence of MR as the probability of a patient having a follow-up TTE may have been greater for a clinical indication; however, we also cannot rule out that we have underestimated the longitudinal recurrence of MR because patients may have had recurrent MR and simply been treated medically.

Although a longitudinal mixed-model analysis to assess ordinal MR across time would have been preferable based on reporting guidelines, the lack of previous echocardiograms before recurrence in a large number of patients made this type of analysis impossible, necessitating dichotomizing outcomes and analyzing them with actuarial methods as if they were discrete events. We also did not include patients in whom repair was attempted and failed. We did not feel that our database was robust enough to impute data, because this would have likely introduced as many errors as it fixed. Regarding reoperations, we did not include patients in whom reoperative mitral surgery was indicated but the patient either refused or was deemed too high risk. Last, it is difficult to compare results between studies because of differing definitions, patient populations, comparator groups, and variation in TTE follow-up.

Assurance of complete and current survival is difficult to obtain in any retrospective study. We carried out an exhaustive and systematic effort to verify survival by contacting

the referring physicians, the patient, or patient's next of kin followed by a search of obituaries at the patients last known address. If we still could not locate the patient, we relied on a search of a current version of the Social Security Death Index. We believe that our mortality data are complete and accurate, but the possibility of missed deaths remains a possibility.

Our study confirms the results of other centers of excellence. Mitral valve repair is associated with excellent survival, is durable with low rates of need for reoperation, and MR appears less likely to recur with posterior leaflet repair. We should be cognizant of these surgical results during this era of ever increasing application of percutaneous mitral valve therapy.

Conflicts of Interest Statement

Drs Bowdish and Cohen have received grant support from Medtronic, Inc, in the last 36 months for an unrelated project. Dr Cohen is on the Scientific Advisory Board and Speakers Bureau of Medtronic Inc. All other authors have nothing to disclose with regard to commercial support.

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Key Words: mitral valve repair, posterior leaflet repair, recurrent mitral regurgitation, mitral valve reoperation, degenerative valve disease

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FIGURE E1. Consolidated Standards of Reporting Trials type flow diagram. *MV*, Mitral valve.

TABLE E1. Distribution of mitral valve replacement and repairs over time

Date of surgery	Mitral valve procedures			
	Replacement	All repairs	Repair: annuloplasty ring (only)	Repair: leaflet repair with or without annuloplasty ring
01/01/1999-12/31/1999	31	3	2	1
01/01/2000-12/31/2000	47	13	7	6
01/01/2001-12/31/2001	53	18	11	7
01/01/2002-12/31/2002	63	25	13	12
01/01/2003-12/31/2003	50	20	10	10
01/01/2004-12/31/2004	48	54	26	28
01/01/2005-12/31/2005	45	46	23	23
01/01/2006-12/31/2006	59	55	22	33
01/01/2007-12/31/2007	47	51	20	31
01/01/2008-12/31/2008	59	49	10	30
01/01/2009-12/31/2009	63	53	29	24
01/01/2010-12/31/2010	61	93	41	52
01/01/2011-12/31/2011	65	85	43	42
01/01/2012-12/31/2012	58	70	27	43
01/01/2013-12/31/2013	60	91	47	44
01/01/2014-12/31/2014	92	62	21	41
01/01/2015-06/30/2015	43	22	3	19
Total	944	810	364	446

TABLE E2. CIs for time dependent figures

	1 y (95% CI)	3 y (95% CI)	5 y (95% CI)	10 y (95% CI)	15 y (95% CI)
Figure 1 All patients	96.9 (94.6-98.2)	95.7 (93.1-97.3)	94.8 (91.8-96.7)	94.0 (90.4-96.2)	94.0 (90.4-96.2)
Figure 2 Any posterior repair	3.0 (1.7-5.9)	3.8 (2.0-6.4)	4.3 (2.3-7.1)	5.7 (3.1-9.3)	5.7 (3.1-9.3)
No posterior repair	1.8 (0.0-8.2)	6.5 (1.7-16.1)	9.6 (3.0-21.1)	25.9 (11.4-43.2)	39.5 (14.0-64.5)
Figure 3 Any posterior repair	4.2 (2.1-7.4)	7.8 (4.2-12.9)	17.2 (9.5-26.9)	33.0 (15.0-52.3)	—
No posterior repair	7.9 (2.0-19.2)	24.2 (8.9-43.5)	40.4 (16.5-63.4)	52.8 (21.8-76.6)	—

CI, Confidence interval.

TABLE E3. Baseline and operative characteristics of study patients with reoperative follow-up and without reoperative follow-up

Characteristic	Reoperative follow-up, n = 364	No reoperative follow-up, n = 82	P value
Age, mean $\pm$ SD (95% CI)	60.38 $\pm$ 13.5 (58.9-61.8)	61.8 $\pm$ 59.2 (59.2-64.4)	.59*
Male, n (%)	239 (65.7)	57 (69.5)	.51†
White, n (%)	289 (79.4)	54 (65.6)	.009†
BMI, mean $\pm$ (95% CI)	26.0 $\pm$ 5.4 (25.4-26.6)	26.2 $\pm$ 4.2 (25.3-27.2)	.24*
Diabetes, n (%)	29 (8.0)	8 (9.8)	.60†
Posterior repair, n (%)	306 (84.0)	71 (86.6)	.57†
Anterior repair, n (%)	108 (29.7)	24 (29.2)	.94†
Previous MV surgery, n (%)	6 (1.7)	1 (1.2)	.78†
Concurrent procedure, n (%)	119 (32.7)	21 (25.6)	.212†
Concurrent tricuspid valve procedure, n (%)	27 (7.4)	4 (4.9)	.41†
Cardiopulmonary CCT >90 min, n (%)	135 (38.0)	37 (46.3)	.13*
Crossclamp >60 min, n (%)	136 (37.9)	41 (51.6)	.10*
Concurrent other valve surgery, n (%)	43 (11.8)	5 (6.1)	.13†
Concurrent CABG, n (%)	17 (4.7)	4 (4.9)	.94†
Previous cardiac surgery, n (%)	16 (4.4)	7 (8.6)	.17†

SD, Standard deviation; CI, confidence interval; BMI, body mass index; MV, mitral valve; CCT, cross-clamp time; CABG, coronary artery bypass grafting. *Mann-Whitney U test.

†Pearson χ^2 test.

TABLE E4. Baseline and operative characteristics of study patients with and without MR progression follow-up (echocardiogram)

Characteristic	MR progression follow-up, n = 334	No MR progression follow-up, n = 112	P value
Age, mean $\pm$ SD (95% CI)	60.6 $\pm$ 13.2 (59.1-61.9)	60.9 $\pm$ 13.2 (58.4-63.3)	.89*
Male, n (%)	219 (65.6)	77 (68.8)	.54†
White, n (%)	266 (79.6)	77 (68.8)	.018†
BMI, mean $\pm$ (95% CI)	26.0 $\pm$ 5.3 (25.5-26.6)	26.0 $\pm$ 5.0 (25.1-27.0)	.76*
Diabetes, n (%)	27 (8.1)	10 (8.9)	.78†
Posterior repair, n (%)	283 (84.7)	94 (83.9)	.84†
Anterior repair, n (%)	99 (29.6)	33 (29.4)	.97†
Previous MV surgery, n (%)	5 (1.5)	2 (1.8)	.83†
Concurrent procedure, n (%)	109 (32.6)	31 (27.8)	.33†
Concurrent tricuspid valve procedure, n (%)	23 (6.9)	8 (7.1)	.92†
Cardiopulmonary CCT >90 min, n (%)	124 (38.0)	48 (44.0)	.24*
Crossclamp >60 min, n (%)	123 (37.3)	54 (49.1)	.24*
Concurrent other valve surgery, n (%)	38 (11.4)	10 (8.9)	.47†
Concurrent CABG, n (%)	18 (5.4)	3 (2.7)	.24†
Previous cardiac surgery, n (%)	13 (3.4)	10 (8.9)	.04†

MR, Mitral regurgitation; SD, standard deviation; CI, confidence interval; BMI, body mass index; MV, mitral valve; CCT, cross-clamp time; CABG, coronary artery bypass grafting. *Mann-Whitney U test. †Pearson χ^2 test.