Simple versus complex degenerative mitral valve disease

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ABSTRACT

Objectives: At a center where surgeons favor mitral valve (MV) repair for all subsets of leaflet prolapse, we compared results of patients undergoing repair for simple versus complex degenerative MV disease.

Methods: From January 1985 to January 2016, 6153 patients underwent primary isolated MV repair for degenerative disease, 3101 patients underwent primary isolated MV repair for simple disease (posterior prolapse), and 3052 patients underwent primary isolated MV repair for complex disease (anterior or bileaflet prolapse), based on preoperative echocardiographic images. Logistic regression analysis was used to generate propensity scores for risk-adjusted comparisons ($n = 2065$ matched pairs). Durability was assessed by longitudinal recurrence of mitral regurgitation and reoperation.

Results: Compared with patients with simple disease, those undergoing repair of complex pathology were more likely to be younger and female (both P values $< .0001$) but with similar symptoms ($P = .3$). The most common repair technique was ring/band annuloplasty (3055/99% simple vs 3000/98% complex; $P = .5$), followed by leaflet resection (2802/90% simple vs 2249/74% complex; $P < .0001$). Among propensity-matched patients, recurrence of severe mitral regurgitation 10 years after repair was 6.2% for simple pathology versus 11% for complex pathology ($P = .007$), reoperation at 18 years was 6.3% for simple pathology versus 11% for complex pathology, and 20-year survival was 62% for simple pathology versus 61% for complex pathology ($P = .6$).

Conclusions: Early surgical intervention has become more common in patients with degenerative MV disease, regardless of valve prolapse complexity or symptom status. Valve repair was associated with similarly low operative risk and time-related survival but less durability in complex disease. Lifelong annual echocardiographic surveillance after MV repair is recommended, particularly in patients with complex disease. (*J Thorac Cardiovasc Surg* 2018;156:122-9)

Temporal trend of severe postoperative mitral regurgitation (MR) after mitral valve repair.

Central Message

Degenerative mitral valve repair operations have become increasingly durable. However, lifelong annual echocardiographic surveillance is recommended, particularly for patients with complex disease.

Perspective

Mitral valve repair for degenerative disease is associated with excellent survival and low operative risk, regardless of valve prolapse complexity. However, repair of complex disease is still less durable and requires lifelong postoperative annual echocardiographic surveillance.

See Editorial Commentary page 130.

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Degenerative mitral valve disease is the most common indication for mitral valve surgery and is recognized as an important preventable cause of chronic heart failure.¹⁻³

The recent American Heart Association/American College of Cardiology guidelines recommend (class IIA) surgical mitral valve repair for asymptomatic patients with chronic severe primary mitral regurgitation (MR) with preserved

Scanning this QR code will take you to a supplemental video, appendix, figures and tables for the article.

Abbreviations and Acronyms

MR = mitral regurgitation
NYHA = New York Heart Association

left ventricular function (ejection fraction > 60% and end-systolic dimension < 40 mm) in whom the likelihood of a successful and durable repair without residual MR is more than 95%, and expected mortality of <1% when performed at an experienced heart valve center.⁴

Although there is consensus that repair of posterior leaflet prolapse by resection and annuloplasty is reproducible and durable, outcomes after repair of anterior leaflet and bileaflet prolapse are less certain.⁵ Thus, many cardiologists have been reluctant to recommend surgical intervention in asymptomatic patients with anterior or bileaflet prolapse because of perceived inferior surgical outcomes (Video 1).^{1,6} At a center where surgeons favor mitral valve repair for all subsets of leaflet prolapse, we sought to identify temporal trends in characteristics of patients with simple (posterior leaflet prolapse) and complex (anterior or bileaflet prolapse) degenerative MR undergoing mitral valve repair, determine whether postoperative complications differed after repair of simple versus complex disease, assess recurrent MR over time and prevalence of reoperation after repair in each group, compare long-term survival, and identify factors associated with mortality and durability after repair.

PATIENTS AND METHODS

Patients

From January 1, 1985, to January 1, 2016, 6153 patients underwent primary mitral valve repair for degenerative mitral valve disease with leaflet prolapse (Carpentier type II⁷) at Cleveland Clinic. Patients with concomitant tricuspid valve repair (n = 350 [5.7%]), closure of an atrial septal defect or patent foramen ovale (n = 274 [4.5%]), or surgical ablation for atrial fibrillation (n = 750 [12%]) are included, but those with severe mitral annular calcification or undergoing other concomitant cardiac operations are not. These 6153 patients represent 96% of the 6408 patients undergoing primary mitral valve surgery for degenerative disease. The proportion of patients undergoing mitral valve repair has increased steadily, to nearly 100% in recent years (Figure E1).

Cardiologists usually recommend surgical intervention based on complexity of the valve pathology seen in echocardiographic images. Therefore, simple versus complex degenerative mitral valve disease was classified by review of echocardiographic images. Of 6153 patients, 3101 underwent mitral valve repair for simple disease on preoperative echocardiographic imaging, which represents 97% of 3183 patients undergoing mitral valve surgery for simple disease (Figure E2, A), and 3052 underwent mitral valve repair for complex disease, which represents 95% of 3225 patients undergoing mitral valve surgery for complex disease (Figure E2, B).

Surgical Details

Full sternotomy was performed in 2351 patients (39%), partial sternotomy in 1958 (32%), and right minithoracotomy in 693 (11%), and a

VIDEO 1. Simple versus complex degenerative mitral valve disease. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)30896-1/fulltext](https://www.jtcvs.org/article/S0022-5223(18)30896-1/fulltext).

robotic approach was used in 1045 (17%). Details of surgical approaches for patients undergoing less invasive and robotic mitral valve repair have been described previously.⁸⁻¹⁰

The most common repair techniques included band/ring annuloplasty in 6055 (98%), leaflet resection in 5052 (82%), sliding repair in 2576 (42%), insertion of polytetrafluoroethylene chords in 579 (9.4%), chordal transfer in 529 (8.6%), and commissuroplasty in 254 (4.1%). The most common reasons for not using annuloplasty repair were high probability of postrepair systolic anterior motion and valve stenosis due to small size of the annulus. Further details are provided in Appendix E1.

End points

End points included in-hospital mortality and morbidity, longitudinal persistence or recurrence of MR, reoperation after mitral valve repair, and time-related mortality. In-hospital mortality and complications were defined according to the Society of Thoracic Surgeons National Cardiac Database (see http://www.sts.org/sites/default/files/documents/STSAAdultCVDataSpecificationsV2_81.pdf).

A total of 7719 postoperative echocardiograms were available for 3767 patients (91%) in the matched repair group (see Data Analysis and Presentation for matching strategy). However, only a subset of 1085 matched patients have been routinely followed at Cleveland Clinic, with a total of 3370 echocardiograms available. Compared with patients not having follow-up echocardiography, these patients were more likely to be younger and less symptomatic, with a higher prevalence of chordal elongation and use artificial chordae, annuloplasty, and sliding repair techniques (Tables E1 and E2). Details of echocardiographic follow-up are shown in Figures E3 and E4.

For time-related events, patients were followed systematically at 2, 5, 10, 15, and 20 years after surgery by mailed institutional review board-approved questionnaires, telephone interviews, or examination at Cleveland Clinic. Median time for this active follow-up was 6 years, with 25% of survivors followed for more than 10 years and nearly 5% for 20 years (Figure E5).

Data Analysis and Presentation

The analytic strategy included identifying patient characteristics associated with complex disease, generating a cohort of matched patients using propensity scores, and comparing persistent or recurrent MR longitudinally after repair, survival, and reoperation between matched cohorts.¹¹ Data used in these analyses were approved for research by the Cleveland Clinic Institutional Review Board, with patient consent waived. All analyses were performed using SAS statistical software version 9.4 (SAS Institute, Cary, NC) and R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria).¹²

Single Versus Complex Prolapse

Briefly, multivariable logistic regression analysis (PROC LOGISTIC) was used to identify baseline factors from among those listed in [Appendix E2](#) that were associated with complex mitral valve prolapse. To meet assumptions of linearity of ordinal and continuous variables with respect to the logit, we incorporated potentially linearizing transformations of scale in our variable selection strategy. Variable selection, with a *P* value criterion for retention of variables in the model of .05, used bagging (bootstrap aggregation)^{12,13} with automated forward stepwise analysis of 1000 resampled data sets. Variables appearing in at least 50% of analyses were considered reliably statistically significant. This parsimonious model ([Table E3](#)) was amplified to form a semisaturated propensity model by adding factors from each class of variables not already represented (see [Appendix E2](#)).^{14,15} The final model was solved to generate a propensity score for each patient, then used to identify 2065 propensity-matched pairs (68% of possible matched pairs) ([Tables E4](#) and [E5](#), [Figure E6](#), *A* and *B*) with a greedy-matching strategy.¹⁶

In the simple group, patients in the matched cohort were more likely than unmatched patients to be younger and female, had similar preoperative symptoms and cardiac morphology, higher prevalence of preoperative atrial fibrillation and chordal elongation, and similar MV repair techniques ([Table E6](#)). In the complex group, patients in the matched cohort were more likely than unmatched patients to be older and male, with similar preoperative symptoms and cardiac morphology, lower prevalence of preoperative atrial fibrillation and chordal elongation, but similar MV repair techniques ([Table E7](#)).

Longitudinal Analysis of Persistent or Recurrent MR

We analyzed the longitudinal pattern of MR grades on surveillance transthoracic echocardiograms using a nonlinear cumulative logistic mixed model.¹⁷ Prevalence of each MR grade over time was estimated by averaging patient-specific profiles from this model.

Time-Related Events

Nonparametric estimates of survival and reoperation were assessed by the Kaplan-Meier method and parametric estimates by a multiphase hazard model.¹⁸ The parametric model was used to resolve a number of phases of instantaneous risk of death/reoperation (hazard function) and to estimate shaping parameters.

Risk Factor Identification

Risk factors for death, reoperation, and persistent or recurrent MR were identified using the bagging method, with variable selection from those presented in [Appendix E2](#). Procedure characteristics were also included as potential risk factors.

Managing Missing Values

To account for missing values for some variables in multivariate modeling, we performed 5-fold multiple imputation using a Markov chain Monte Carlo technique.¹⁹

Presentation

Categorical variables are summarized as frequency and percentage and were compared using the χ^2 test or Fisher exact test when fewer than 5 events were observed in either group. Continuous variables are summarized as mean $\pm$ standard deviation or equivalently as 15th, 50th (median), and 85th percentiles when their distribution was skewed, but all were compared using the Wilcoxon rank-sum test to account conservatively for nonnormality of distributions. Mortality and reoperation estimates are accompanied by an asymmetric 68% confidence interval, comparable to ± 1 standard error. Trends are displayed using a smoothing spline (R statistical software).²⁰

RESULTS

Complex Versus Simple Degenerative Mitral Valve Disease

Primary isolated mitral valve repair was performed in 3101 patients with simple disease and 3052 patients with complex disease observed by preoperative echocardiography. The percentage of patients diagnosed echocardiographically with complex disease declined in the first decade of our experience ([Figure E7](#)). Compared with patients with simple disease, those who underwent repair for complex pathology were more likely to be younger (mean age, 56 ± 13 years vs 58 ± 11 years) and female (38% vs 24%), with a higher prevalence of leaflet calcification (2.2% vs 1.4%), severe tricuspid valve regurgitation (5.1% vs 3.4%), and preoperative atrial fibrillation (15% vs 12%) ([Table 1](#)).

Compared with patients with simple disease, those who underwent mitral valve repair for complex disease had similar left ventricular end-systolic volume index (25 ± 12 mL/m vs 24 ± 11 mL/m; *P* = .4) and left ventricular mass index (128 ± 35 g/m vs 128 ± 36 g/m; *P* = .8).

The most common type of mitral valve repair was ring/band annuloplasty (99% in the simple group vs 98% in the complex group), followed by leaflet resection (90% in the simple group vs 74% in the complex group) ([Table 2](#)).

Temporal Trends of Preoperative Characteristics

Cardiac morphology. Preoperative echocardiographic features of patients with degenerative mitral valve disease have changed over time. Left ventricular size and mass decreased steadily over the first decade of our experience in the entire cohort ([Figure 1](#), *A* and *B*) (*P* < .004) as well as in the simple and complex groups ([Figure E8](#), *A* and *B*, and [Figure E9, *A* and *B*\).](#)

Clinical presentation. The proportion of patients in New York Heart Association (NYHA) functional class III or IV on presentation declined over the study period, from about 30% in 1885 to 10% in 2016 ([Figure 2](#), *A*) (*P* < .0001). The temporal trend in NYHA functional class for patients with simple disease was similar to that for patients with complex disease ([Figure 2](#), *B* and *C*).

TABLE 1. Patient characteristics

Characteristic	Simple disease (n = 3101)		Complex disease (n = 3052)		P value
	n*	n (%) or mean ± standard deviation	n*	n (%) or mean ± standard deviation	
Demographic characteristic					
Age (y)	3101	58 ± 11	3052	56 ± 13	<.0001
Female	3101	744 (24)	3052	1160 (38)	<.0001
Cardiac comorbidity					
LV ejection fraction (%)	2810	59 ± 6.5	2651	58 ± 6.6	<.0001
LVESVI (mL/m)	2282	24 ± 11	2162	25 ± 12	.4
LV mass index (g/m)	2297	128 ± 36	2157	128 ± 35	.8
Heart failure	3100	499 (16)	3052	415 (14)	.006
Atrial fibrillation	2902	342 (12)	2842	436 (15)	<.0001
NYHA functional class	3080		3041		.3
I		1161 (38)		1121 (37)	
II		1566 (51)		1544 (51)	
III		310 (10)		343 (11)	
IV		43 (1.4)		33 (1.1)	
Noncardiac comorbidity					
Hypertension	3003	1405 (47)	2884	1068 (37)	<.0001
COPD	3002	175 (5.8)	2884	176 (6.1)	.7
Diabetes					
Insulin-treated	3055	13 (0.43)	2997	9 (0.30)	.4
Noninsulin-treated	3055	89 (2.9)	2997	50 (1.7)	.001
Creatinine (mg/dL)	2971	1.02 ± 0.46	2842	0.98 ± 0.57	<.0001

LV, Left ventricle; LVESVI, left ventricular end-systolic volume index; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. *Patients with data available.

In-hospital outcomes. Among propensity-matched patients, the simple and complex groups experienced similar in-hospital mortality (0.048% vs 0.097%), occurrence of

stroke (0.87% vs 1.4%), new-onset atrial fibrillation (28% vs 29%), respiratory failure (1.4% vs 2.4%), septicemia (0.20% vs 0.25%), reexploration for bleeding

TABLE 2. Mitral valve pathophysiology and repair techniques

Characteristic	Simple disease (n = 3101)		Complex disease (n = 3052)		P value
	n*	n (%)	N*	n (%)	
Pathophysiology					
Regurgitation grade	2979		2849		<.0001
Moderate		37 (1.2)		89 (3.1)	
Moderate to severe		393 (13)		709 (25)	
Severe		2549 (86)		2051 (72)	
Leaflet cleft	2884	93 (3.2)	2876	111 (3.9)	.19
Chordal rupture	2884	2225 (77)	2876	1521 (53)	<.0001
Chordal elongation	2884	614 (21)	2876	849 (30)	<.0001
Leaflet calcification	2884	40 (1.4)	2876	63 (2.2)	.02
Repair technique					
Annuloplasty	3101	3055 (99)	3052	3000 (98)	.5
Leaflet resection	3101	2803 (90)	3052	2249 (74)	<.0001
Sliding repair	3101	1199 (39)	3052	1377 (45)	<.0001
Artificial chordae	3101	180 (5.8)	3052	399 (13)	<.0001
Chordal transfer	3101	59 (1.9)	3052	470 (15)	<.0001
Commissuroplasty	3101	76 (2.5)	3052	178 (5.8)	<.0001
Incision characteristic					
Full sternotomy	3041	1075 (35)	3006	1276 (42)	<.0001
Thoracotomy	3041	377 (12)	3006	316 (11)	<.0001
Partial sternotomy	3041	986 (32)	3006	972 (32)	<.0001
Robotic	3041	603 (20)	3006	442 (15)	<.0001

*Patients with data available.

FIGURE 1. Temporal trends among patients undergoing mitral valve repair. A, Left ventricular (LV) end-systolic volume index. *Solid line* is a smoothing spline curve and *filled circles* represent the mean baseline LV end-systolic volume index each year. B, LV mass index.

(2.2% vs 2.7%), renal failure (0.058% vs 0.17%), and length of intensive care unit stay (15th, 50th, and 85th percentiles, 22, 24, and 28 hours vs 21, 24, and 28 hours, respectively, for both groups) after repair ($P \geq .05$ for all) (Table 3).

Recurrent MR. Prevalence of persistent or recurrent MR demonstrated an early increase within the first month after repair followed by a slow progression in the months and years thereafter (Figure E10, A and B). Among propensity-matched patients, 95% of those in the simple group and 93% of those in the complex group had no or mild MR within 1 month after valve repair. By 10 years, an estimated 86% in the simple group had no or mild MR, 7.9% had moderate MR, and 6.2% had severe MR, versus 77% with no or mild MR, 12% with moderate MR, and 11% with severe MR in the complex group ($P = .01$ in the early phase and $P = .007$ in the late phase after repair) (Figure 3).

FIGURE 2. Temporal trend in New York Heart Association (NYHA) functional class among patients presenting for mitral valve repair. *Solid line* is a smoothing spline curve and *symbols* represent the mean percentage of patients with NYHA data available each year. A, All patients. B, Patients with simple disease. C, Patients with complex disease.

Incremental risk factors for early persistence or progression of MR in the entire cohort were higher preoperative right ventricular systolic pressure and left atrial volume

TABLE 3. Postoperative in-hospital complications among propensity-matched patients

Complication	Simple disease (n = 2065)		Complex disease (n = 2065)		P value
	n*	n (%)	n*	n (%)	
Death	2065	1 (0.048)	2065	2 (0.097)	.4
Stroke	2065	18 (0.87)	2065	28 (1.4)	.14
Atrial fibrillation	1724	491 (28)	1717	491 (29)	.9
Respiratory complication	1383	19 (1.4)	1443	34 (2.4)	.05
Septicemia	1989	4 (0.20)	1970	5 (0.25)	.7
Reoperation for bleeding	2065	45 (2.2)	2065	56 (2.7)	.3
Renal failure	1729	1 (0.058)	1749	3 (0.17)	.6

*Patients with data available.

index, earlier date of operation, placement of artificial chordae, complex disease, and not having leaflet resection in the late phase (Table E8 and Figure E11, A and B).

Reoperation. Among propensity-matched patients, 97 underwent reoperation after mitral valve repair. Indications were recurrence of severe MR in 80 patients (82%) (tear in leaflet in 14 patients [14%], failure of artificial chord in 6 patients [6%], failure of annuloplasty in 2 patients [2%], progression of degenerative disease in 15 patients [15%], unknown reason in 43 patients [44%], symptomatic systolic anterior motion in 9 patients [9%], severe MV stenosis in 4 patients [4%], and endocarditis in 4 patients [4%]). Risk of reoperation at 18 years after repair was 6.3% for those with simple disease versus 11% for those with complex disease ($P = .03$ in the early hazard phase and $P = .13$ in the late rising hazard phase) (Figure E12).

Incremental risk factors for reoperation in the entire cohort were earlier date of operation, higher preoperative NYHA functional class, and higher preoperative left atrial

volume index in the early phase, and mitral valve repair without annuloplasty and without leaflet resection in the late phase. Complex disease was a risk factor for reoperation both early and late after repair (Table E9 and Figure E13, A and B).

Survival. Among propensity-matched patients, survival at 20 years after repair was 62% for those with simple disease versus 61% for those with complex valve disease ($P = .6$ in both the constant and late phases) (Figure 4).

Incremental risk factors for death in the entire cohort were older age, lower preoperative left ventricular ejection fraction, heart failure, prior stroke, and earlier date of operation in the constant phase, and higher preoperative body mass index, prior myocardial infarction, carotid disease, and higher preoperative tricuspid and pulmonary valve regurgitation in the late hazard phase. Complexity of the valve was not associated with death in either phase (Table E10).

DISCUSSION

Key Findings

In recent years, early surgical intervention—before development of symptoms, atrial fibrillation, or changes in left ventricular structure and function—has become more common in patients with degenerative mitral valve disease, regardless of complexity of the degenerative lesion. Valve repair was associated with similarly low operative risk and better time-related survival, but greater progression of MR and late reoperations in complex versus simple disease. Earlier date of operation and placing artificial chordae in complex disease, and not having leaflet resection and annuloplasty were associated with lower durability of MV repair.

Current Clinical Practice

Although there is no debate among experts concerning mitral valve repair for severe symptomatic degenerative MR (class IB recommendation),⁴ discordance persists in mainstream clinical practice regarding early correction of severe asymptomatic degenerative MR. Approximately

FIGURE 3. Temporal trend of severe postoperative mitral regurgitation (MR) after mitral valve repair in propensity-matched patients. Solid lines represent ensemble average of percentage of patients with severe postoperative MR. Symbols represent data grouped (without regard to repeated measurements) within time frames to provide a crude verification of model fit. Blue line indicates matched simple prolapse group and red line indicates matched complex prolapse group.

FIGURE 4. Mortality after mitral valve repair in propensity-matched patients. Each *symbol* represents a death positioned on the vertical axis by the Kaplan-Meier estimator; *vertical bars* are 68% confidence limits equivalent to ± 1 standard error. *Solid lines* are parametric hazard estimates enclosed within a dashed 68% confidence band. *Blue lines and circles* indicate simple prolapse group and *red lines and circles* indicate complex prolapse group.

30% to 60% of such patients in the United States and 30% in Europe undergo surgery. Although American Heart Association/American College of Cardiology guidelines⁴ provide a class IIA recommendation for early operation in asymptomatic patients, European guidelines²¹ do not provide a strong endorsement of this course. However, surgical referral after development of left ventricle enlargement and dysfunction results in excess early and late mortality as well as increased risk of heart failure, as we also observed in our study.^{1,4}

In clinical practice, the site of prolapse (ie, anterior, posterior, or bileaflet) has a potential influence on the likelihood of surgical referral in patients with severe asymptomatic MR. Although cardiologists agree that early surgical referral of patients with simple degenerative mitral valve disease (posterior prolapse) is supported by evidence, many have been reluctant to recommend surgical intervention for asymptomatic patients with complex disease (ie, anterior or bileaflet prolapse), fearing that surgical outcomes are inferior to watchful waiting. Patients with complex disease previously presented with more symptoms and greater changes in cardiac structure and function than did patients with simple disease and experienced slightly inferior outcomes.^{5,22,23} Recently, patients have been referred for early correction of severe MR regardless of the type and extent of valve prolapse, as shown in this study. We demonstrate that this practice does not compromise outcomes.

Durability of Repair

Historically, repair of an anterior leaflet has been more challenging than posterior leaflet repair and has been

accompanied by reduced durability.^{5,23-25} Anterior repair techniques have evolved from chordal shortening and chordal transfer to insertion of polytetrafluoroethylene chordae.^{5,26-28} Creation of artificial chordae has been associated with excellent durability and is amenable to less invasive approaches, making it our preferred technique in recent years.

In an earlier series,⁵ we compared 252 isolated anterior repairs with 2650 isolated posterior repairs and found that recurrence of MR was more likely early after anterior repair. In the current study, we extended our experience for 10 more years and found similar results. However, more recent operation was associated with higher durability. Possible explanations for these findings include evolution of anterior leaflet repair techniques and increased surgeon experience.

Patients with bileaflet prolapse were included in the group with complex disease. Many of these patients have Barlow disease. Although such valves appear quite complex, successful repair is often achievable by a posterior leaflet repair alone (Appendix E3). In particular, when the valve exhibits bileaflet prolapse and the MR jet is centrally or anteriorly directed, posterior leaflet resection (with or without a sliding repair) and annuloplasty generally result in a successful repair. In contrast, patients with a posteriorly directed MR jet require an anterior leaflet procedure.

Survival

Evidence supporting similar survival after repair for simple and complex mitral valve disease has accumulated over the past decades.^{5,29-31} In earlier reports, unadjusted survival of patients presenting with anterior disease was inferior to that of those presenting with posterior disease. This was likely attributable to more pronounced changes in cardiac structure and function at the time of surgical referral.⁵ Our current work demonstrates similar excellent survival among patients with simple and complex disease as long as they are referred before developing left ventricle damage and dysfunction.

Limitations

This was a nonrandomized clinical study with possible selection bias. However, our approach was to consider degree of prolapse as a natural experiment and to use propensity matching of variables other than the prolapse itself to propensity match patients for assessing outcomes. Nevertheless, this methodology cannot account for unmeasured or undocumented variables. Late postoperative echocardiographic follow-up was limited to patients who routinely returned to our institution for surveillance clinic visits (see Appendix E3). However, sufficient echocardiographic data were available to estimate valve durability to 10 years. Furthermore, because of limitations of joint modeling techniques with longitudinal measures and survival, the analysis

of MR persistence or progression does not account for death as a competing risk. Death, although uncommon, was another potential limitation if it was informative of recurring MR.

This study extended over more than 2 decades, during which time mitral valve repair techniques changed. As such, date of operation was included in the propensity model. After matching, there was no statistically significant difference between the simple and complex disease groups.

CONCLUSIONS

Mitral valve repair for degenerative MR is associated with low operative risk and excellent time-related survival but lower repair durability in complex disease. Mitral valve repair for complex disease requires lifelong postoperative annual echocardiographic surveillance.

Conflict of Interest Statement

Dr Gillinov is a consultant for CryoLife Technologies, Kennesaw, Ga; Edwards Lifesciences, Irvine, Calif; Medtronic, Minneapolis, Minn; St Jude Medical, Minneapolis, Minn; Abbott Laboratories, Chicago, Ill; and AtriCure, Mason, Ohio; and receives research funding from Abbott. Dr Mick is a consultant for Medtronic. All other authors have nothing to disclose with regard to commercial support.

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Key Words: mitral valve repair, mitral valve surgery

APPENDIX E1. ECHOCARDIOGRAPHIC VERSUS SURGICAL FINDINGS

Both preoperative transthoracic echocardiographic and surgical findings are subject to observation bias. Although echocardiograms may show prolapse above the annulus plane, this visual interpretation depends on image quality and orientation as well as interobserver variability. What a surgeon finds and the repair performed may or may not be consistent with preoperative diagnosis and intraoperative echocardiographic findings under altered loading conditions.

Thus, we focused our analyses on the cardiologic diagnosis that patients arrive with in the operating room. In the simple prolapse group, 2939 of 3101 patients underwent repair solely of the posterior leaflet, and 7, 79, and 76 underwent anterior-only repair, bileaflet repair, and annuloplasty-only repair, respectively. In the complex prolapse group, 652 of 3052 patients underwent bileaflet repair, and 1962, 308, and 130 underwent posterior-only repair, anterior-only repair, and annuloplasty-only repair.

Preoperative echocardiographic diagnosis versus surgical findings

Repair performed	Prolapse on preoperative echocardiogram		
	Anterior only (n = 424)	Posterior only (n = 3101)	Bileaflet (n = 2628)
Posterior only	104 (25)	2939 (95)	1858 (71)
Anterior only	211 (50)	7 (0.23)	97 (3.7)
Bileaflet	74 (17)	79 (2.5)	578 (22)
Annuloplasty only	35 (8.3)	76 (2.5)	95 (3.6)

Values are presented as n (%).

APPENDIX E2. VARIABLES INCLUDED IN THE ANALYSES

*Variables used in the propensity model; procedure variables were considered as risk factors only for the outcome models (mortality, reoperation, and mitral valve regurgitation).

Patient Variables

Demographic characteristics: Age (y),* sex,* race (white,* black,* or other), weight (kg), height (cm), weight/height ratio,* body surface area (m²), and body mass index.

Symptoms: New York Heart Association functional class (I-IV).*

Pathology aortic valve regurgitation (yes/no,* grade*), mitral valve regurgitation grade,* pulmonary valve regurgitation (yes/no),* and tricuspid valve regurgitation (yes/no,* grade*).

Ventricular dysfunction: Prior myocardial infarction.*

Cardiac comorbidity: Atrial fibrillation,* complete heart block or pacer,* ventricular arrhythmia,* heart failure,* and history of endocarditis.*

Noncardiac comorbidity: Peripheral arterial disease,* carotid disease,* hypertension,* pharmacologically treated diabetes,* chronic obstructive pulmonary disease,* history of smoking,* stroke,* creatinine (mg/dL), blood urea nitrogen (mg/dL),* bilirubin (mg/dL),* creatinine clearance (mL/min),* glomerular filtration rate (modification of diet in renal disease; mL/min/1.73 m²), hematocrit (%),* total cholesterol (mg/dL),* high-density lipoprotein cholesterol (mg/dL),* low-density lipoprotein cholesterol (mg/dL),* and triglycerides (mg/dL).*

Coronary artery disease: Systems with > 50% stenosis (left anterior descending coronary artery,* left circumflex coronary artery,* and right coronary artery*), number of systems with > 50% stenosis.

Mitral valve pathologies: Calcification,* leaflet calcification,* thickening/fibrosis,* chordal thickening/fibrosis,* leaflet thickening/fibrosis,* chordal elongation,* cleft leaflet,* dilated annulus,* chordal rupture,* and left ventricular enlargement.*

Right ventricular function: Systolic pressure (mm Hg).*

Left Ventricle Variables

Structure: Inner diameter in diastole (cm),* inner diameter in systole (cm),* diastolic volume (mL),* systolic volume (mL),* diastolic volume index (mL/m),* systolic volume index (mL/m), and calculated left ventricle relative wall thickness.*

Function: Fractional shortening,* left ventricular ejection fraction (%).*

Hypertrophy: Mass (g), mass index (g/m),* posterior wall thickness (cm),* and septal thickness (cm).*

Left Atrial Variables

Size: Left atrial diameter (cm), calculated unscaled left atrial volume (mL), and unscaled left atrial volume index (mL/m).*

Experience date of operation (years since January 1, 1985).*

Procedure Variables

Operation: Tricuspid valve surgery, any atrial fibrillation procedure, and congenital atrial septal defect/patent foramen ovale suture closure.

Repair techniques: Annuloplasty, leaflet resection, triangular resection, sliding repair, artificial chordae, chordal transfer, and commissuroplasty.

APPENDIX E3. LONGITUDINAL ECHOCARDIOGRAPHIC ASSESSMENT OF MITRAL VALVE REGURGITATION AFTER REPAIR

Because Cleveland Clinic is a high-volume referral center for mitral valve repair, most of our patients come from outside our region. Therefore, their follow-up surveillance is at their local centers. It has rarely been possible to obtain follow-up echocardiographic images or even reports, so we have estimated residual or recurrent mitral regurgitation based on echocardiograms obtained during follow-up surveillance at Cleveland Clinic. As seen in Figure E4, these echocardiograms were obtained for the most part during routine yearly clinic visits.

Patients followed at our institution were slightly older with a slightly higher ejection fraction, and had more heart failure, renal disease, and diabetes than patients followed elsewhere. They also experienced more chordal disease (Tables E1 and E2).

A

B

FIGURE E2. Temporal trend of mitral valve repair. *Solid line* is a smoothing spline curve, and *filled circles* represent mean percentage of patients with a mitral valve repair each year. A, Patients with simple disease. B, Patients with complex disease.

FIGURE E1. Temporal trend of mitral valve repair for all patients with isolated degenerative disease. *Solid line* is a smoothing spline curve, and *filled circles* represent percentage of patients with a mitral valve repair each year.

FIGURE E3. Number of propensity-matched patients with mitral regurgitation (MR) records available at and beyond various time points, and number of MR records available for analysis.

FIGURE E4. Number of patients with postoperative echocardiograms at monthly intervals. Note yearly increases in frequency of echocardiographic measurements, typical of regularly scheduled follow-up examinations. A, Entire cohort. B, Propensity-matched cohort.

FIGURE E5. Goodness of follow-up over the study period. Patients are represented by blue circles. Nearly solid diagonal line represents those last updated at last systematic anniversary-type follow-up at 2 and 5 years and at 5-year increments to 20 years.

FIGURE E7. Temporal trend of complex mitral valve prolapse. Solid line is a smoothing spline curve, and filled circles represent percentage of patients with complex prolapse disease each year.

FIGURE E6. Quality of propensity matching of patients undergoing simple versus complex mitral valve repair. A, Mirrored histogram of distribution of propensity scores for simple and complex groups. Shaded areas represent 2065 matched patient pairs. Unshaded areas represent unmatched patients. B, Standardized difference of selected variables before and after matching, illustrating good matching. BMI, Body mass index; MR, mitral regurgitation; EF, ejection fraction; AFib, atrial fibrillation; STD, standardized.

A

B

FIGURE E8. Temporal trend in left ventricle (LV) end-systolic volume index among patients presenting with simple and complex mitral valve prolapse. *Solid line* is a smoothing spline curve, and *filled circles* represent mean values each year. A, Patients with simple disease. B, Patients with complex disease.

A

B

FIGURE E9. Temporal trend in left ventricular mass index among patients presenting with simple and complex mitral valve prolapse. *Solid line* is a smoothing spline curve, and *filled circles* represent mean values each year. A, Patients with simple disease. B, Patients with complex disease. LV, Left ventricular.

FIGURE E10. Temporal trend of severe postoperative mitral regurgitation (MR) after mitral valve repair in propensity-matched patients. *Solid lines* represent parametric ensemble average of percentage of patients with severe postoperative MR. *Symbols* represent data grouped (without regard to repeated measurements) within time frames to provide a crude verification of model fit. No/trace MR is denoted by *blue line and circles*, mild MR is denoted by *green line and triangles*, moderate MR is denoted by *orange line and squares*, and severe MR is denoted by *red line and diamonds*. A, Matched patients with simple disease. B, Matched patients with complex disease.

FIGURE E11. Temporal trend of severe postoperative mitral regurgitation (MR) after mitral valve repair. *Solid lines* represent parametric ensemble average of percent of patients with severe postoperative MR. These nomograms are based on the multivariable equation in [Table E8](#). Variables held constant are race other than black, no prior myocardial infarction, preoperative unscaled left atrial volume indexed by body surface area 29 mL/m, preoperative creatinine clearance (Cockcroft-Gault) 93 mL/min, preoperative right ventricular systolic pressure 40 mm Hg, and date of operation January 2005. A, Patients with simple disease. Preoperative right ventricular systolic pressure 40 mm Hg, and date of operation January 2005. B, Patients with complex disease.

FIGURE E12. Reoperation after mitral valve repair in propensity-matched patients. Each *symbol* represents a reoperation positioned on the vertical axis by the Kaplan-Meier estimator; *vertical bars* are 68% confidence limits equivalent to ± 1 standard error. *Solid lines* are parametric hazard estimates enclosed within a dashed 68% confidence band. Simple prolapse group is denoted by *blue lines and circles* and complex prolapse group is denoted by *red lines and circles*.

FIGURE E13. Reoperation after mitral valve repair. *Solid lines* are parametric hazard estimates. These nomograms are based on the multivariable equation in [Table E9](#). Variables held constant are New York Heart Association functional class II, no prior myocardial infarction, no preoperative pulmonary valve regurgitation, preoperative unscaled left atrial volume indexed by body surface area 29 mL/m, preoperative blood urea nitrogen 18 mg/dL, preoperative creatinine clearance (Cockcroft-Gault) 93 mL/min, preoperative hematocrit 41%, annuloplasty, and date of operation January 2005. A, Patients with simple disease. B, Patients with complex disease.

TABLE E1. Matched cohort with and without postoperative echocardiogram (postop echo)

Characteristic	Matched cohort without postop echo (n = 363)		Matched cohort with postop echo (n = 3767)		P value
	n*	n (%) or mean $\pm$ standard deviation	n*	n (%) or mean $\pm$ standard deviation	
Demographic					
Age (y)	363	60 $\pm$ 12	3767	57 $\pm$ 12	<.0001
Female	363	115 (32)	3767	1076 (29)	.2
Cardiac comorbidity					
LV ejection fraction (%)	135	57 $\pm$ 7.8	3585	58 $\pm$ 6.6	.02
LVESVI (mL/m)	88	24 $\pm$ 10	2941	24 $\pm$ 11	.5
LV mass index (g/m)	87	132 $\pm$ 43	2952	128 $\pm$ 35	.8
Heart failure	363	113 (31)	3767	457 (12)	<.0001
Atrial fibrillation	336	74 (22)	3513	419 (12)	<.0001
NYHA functional class	362		3747		.0005
I		107 (30)		1456 (39)	
II		195 (54)		1881 (50)	
III		54 (15)		370 (9.9)	
IV		6 (1.7)		40 (1.1)	
Noncardiac comorbidity					
Hypertension	261	84 (32)	3698	1564 (42)	.001
COPD	261	7 (2.7)	3698	232 (6.3)	.02
Diabetes					
Insulin-treated	352	2 (0.57)	3706	13 (0.35)	.4
Noninsulin-treated	352	6 (1.7)	3706	78 (2.1)	.6
Creatinine (mg/dL)	248	1.13 $\pm$ 0.68	3662	0.99 $\pm$ 0.45	<.0001
Pathophysiology					
Regurgitation grade	245		3689		.01
Moderate		9 (3.7)		50 (1.4)	
Moderate to severe		43 (18)		622 (17)	
Severe		193 (79)		3017 (82)	
Leaflet cleft	357	6 (1.7)	3515	132 (3.8)	.04
Chordal rupture	357	266 (75)	3515	2394 (68)	.01
Chordal elongation	357	80 (22)	3515	864 (25)	.4
Leaflet calcification	357	9 (2.5)	3515	58 (1.7)	.2
Repair techniques					
Annuloplasty	363	330 (91)	3767	3727 (99)	<.0001
Leaflet resection	363	318 (88)	3767	3102 (82)	.01
Sliding repair	363	57 (16)	3767	1680 (45)	<.0001
Artificial chordae	363	14 (3.9)	3767	387 (10)	<.0001
Chordal transfer	363	45 (12)	3767	306 (8.1)	.005
Commissuroplasty	363	6 (1.7)	3767	163 (4.3)	.01

LV, Left ventricular; LVESVI, left ventricular end-systolic volume index; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. *Patients with data available.

TABLE E2. Matched cohort with and without routine Cleveland Clinic follow-up postdischarge echocardiogram (echo)

Characteristic	Matched cohort without postdischarge echo (n = 2682)		Matched cohort with postdischarge echo (n = 1085)		P value
	n*	n (%) or mean $\pm$ standard deviation	n*	n (%) or mean $\pm$ standard deviation	
Demographic					
Age (y)	2682	57 $\pm$ 12	1085	58 $\pm$ 11	.002
Female	2682	748 (28)	1085	328 (30)	.15
Cardiac comorbidity					
LV ejection fraction (%)	2639	59 $\pm$ 6.5	946	58 $\pm$ 6.8	<.0001
LVESVI (mL/m)	2253	24 $\pm$ 11	688	25 $\pm$ 11	.02
LV mass index (g/m)	2260	128 $\pm$ 35	692	129 $\pm$ 34	.8
Heart failure	2682	296 (11)	1085	161 (15)	.001
Atrial fibrillation	2546	272 (11)	967	147 (15)	.0002
NYHA functional class	2662		1085		.002
I		1080 (41)		376 (35)	
II		1312 (49)		569 (52)	
III		241 (9.1)		129 (12)	
IV		29 (1.1)		11 (1.0)	
Noncardiac comorbidity					
Hypertension	2675	1114 (42)	1023	450 (44)	.2
COPD	2675	155 (5.8)	1023	77 (7.5)	.05
Diabetes					
Insulin-treated	2645	6 (0.23)	1061	7 (0.66)	.04
Noninsulin-treated	2645	47 (1.8)	1061	31 (2.9)	.03
Creatinine (mg/dL)	2654	0.97 $\pm$ 0.36	1008	1.02 $\pm$ 0.63	.01
Pathophysiology					
Regurgitation grade	2673		1016		.7
Moderate		39 (1.5)		11 (1.1)	
Moderate to severe		448 (17)		174 (17)	
Severe		2186 (82)		831 (82)	
Leaflet cleft	2471	99 (4.0)	1044	33 (3.2)	.2
Chordal rupture	2471	1660 (67)	1044	734 (70)	.07
Chordal elongation	2471	579 (23)	1044	285 (27)	.02
Leaflet calcification	2471	41 (1.7)	1044	17 (1.6)	>.9
Repair technique					
Annuloplasty	2682	2675 (100)	1085	1052 (97)	<.0001
Leaflet resection	2682	2224 (83)	1085	878 (81)	.14
Sliding repair	2682	1240 (46)	1085	440 (41)	.002
Artificial chordae	2682	261 (9.7)	1085	126 (12)	.08
Chordal transfer	2682	189 (7.0)	1085	117 (11)	.0001
Commissuroplasty	2682	124 (4.6)	1085	39 (3.6)	.16

LV, Left ventricle; LVESVI, left ventricular end-systolic volume index; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. *Patients with data available.

TABLE E3. Preoperative factors associated with simple and complex disease

Factor	Estimate $\pm$ standard error	P value	Reliability (%) [*]
Simple disease			
Male	-0.19 ± 0.070	.006	81
Older age [†]	1.1 ± 0.13	<.0001	100
Larger weight/height ratio [‡]	-1.5 ± 0.19	<.0001	100
Higher mitral valve regurgitation grade	-0.49 ± 0.076	<.0001	100
Chordal rupture	-0.85 ± 0.064	<.0001	100
Heart failure	-0.30 ± 0.082	.0003	73
Higher ejection fraction (%) [§]	-0.22 ± 0.099	.02	70
Higher triglycerides (mg/dL)	-0.0010 ± 0.00045	.02	79
Earlier time to index operation	-0.23 ± 0.057	<.0001	99
Complex disease			
Higher TV regurgitation grade	0.11 ± 0.037	.004	99
Mitral valve pathology			
Chordal elongation	0.34 ± 0.065	<.0001	100
Dilated annulus	0.40 ± 0.082	<.0001	100
Leaflet thickening	0.36 ± 0.082	<.0001	94
Atrial fibrillation	0.30 ± 0.087	.0005	87
Complete heart block	0.92 ± 0.36	.01	77
Stroke	0.51 ± 0.21	.02	73

TV, Tricuspid valve. ^{*}Percent of times factor appeared in 1000 bootstrap models. [†](50/age), inverse transformation. [‡]Ln(weight/height ratio), natural logarithmic transformation. [§](Ejection fraction/50)², squared transformation. ^{||}Ln(time to index operation), natural logarithmic transformation.

TABLE E4. Patient characteristics: Propensity matched

Characteristic	Simple disease (n = 2065)		Complex disease (n = 2065)		P value
	n*	n (%) or mean ± standard deviation	n*	n (%) or mean ± standard deviation	
Demographic					
Age (y)	2065	58 ± 12	2065	57 ± 12	.4
Female	2065	595 (29)	2065	596 (29)	>.9
Cardiac comorbidity					
LV ejection fraction (%)	1860	58 ± 6.6	1860	58 ± 6.6	.5
LVESVI (mL/m)	1507	24 ± 11	1522	24 ± 11	.6
LV mass index (g/m)	1519	128 ± 34	1520	129 ± 36	.7
Heart failure	2065	277 (13)	2065	293 (14)	.5
Atrial fibrillation	1918	246 (13)	1931	247 (13)	>.9
NYHA functional class	2051		2058		.6
I		781 (38)		782 (38)	
II		1047 (51)		1029 (50)	
III		199 (9.7)		225 (11)	
IV		24 (1.2)		22 (1.1)	
Noncardiac comorbidity					
Hypertension	1989	823 (41)	1970	825 (42)	.8
COPD	1989	132 (6.6)	1970	107 (5.4)	.11
Diabetes					
Insulin-treated	2034	8 (0.39)	2024	7 (0.35)	.8
Noninsulin-treated	2034	43 (2.1)	2024	41 (2.0)	.8
Creatinine (mg/dL)	1966	1.0 ± 0.48	1944	0.99 ± 0.46	.7

LV, Left ventricle; LVESVI, left ventricular end-systolic volume index; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. ^{*}Patients with data available.

TABLE E5. Mitral valve pathophysiology and repair techniques: Propensity matched

Characteristic	Simple disease (n = 2065)		Complex disease (n = 2065)		P value
	n*	n (%)	n*	n (%)	
Pathophysiology					
Regurgitation grade	1976		1958		.5
Moderate		33 (1.7)		26 (1.3)	
Moderate to severe		323 (16)		342 (17)	
Severe		1620 (82)		1590 (81)	
Leaflet cleft	1936	65 (3.4)	1936	73 (3.8)	.5
Dilated annulus	1936	275 (14)	1936	263 (14)	.6
Chordal rupture	1936	1316 (68)	1936	1344 (69)	.3
Chordal elongation	1936	474 (24)	1936	470 (24)	.9
Leaflet calcification	1936	36 (1.9)	1936	31 (1.6)	.5
Repair techniques that were not included in propensity analysis					
Annuloplasty	2065	2030 (98)	2065	2027 (98)	.7
Leaflet resection	2065	1849 (90)	2065	1571 (76)	<.0001
Sliding repair	2065	803 (39)	2065	934 (45)	<.0001
Artificial chordae	2065	118 (5.7)	2065	283 (14)	<.0001
Chordal transfer	2065	44 (2.1)	2065	307 (15)	<.0001
Commissuroplasty	2065	50 (2.4)	2065	119 (5.8)	<.0001
Incision characteristic					
Full sternotomy	2023	711 (35)	2031	810 (40)	<.0001
Thoracotomy	2023	232 (11)	2031	225 (11)	<.0001
Partial sternotomy	2023	691 (34)	2031	680 (33)	<.0001
Robotic	2023	3899 (19)	2031	316 (16)	<.0001

*Patients with data available.

TABLE E6. Simple degenerative mitral valve disease: Unmatched versus propensity matched

Characteristic	Simple disease unmatched (n = 1036)		Simple disease matched (n = 2065)		P value
	n*	n (%) or mean $\pm$ standard deviation	n*	n (%) or mean $\pm$ standard deviation	
Demographic					
Age (y)	1036	60 $\pm$ 10	2065	58 $\pm$ 12	<.0001
Female	1036	149 (14)	2065	595 (29)	<.0001
Cardiac comorbidity					
LV ejection fraction (%)	950	59 $\pm$ 6.4	1860	58 $\pm$ 6.6	.01
LVESVI (mL/m)	775	25 $\pm$ 12	1507	24 $\pm$ 11	.4
LV mass index (g/m)	778	128 $\pm$ 39	1519	128 $\pm$ 34	.7
Heart failure	1035	222 (21)	2065	277 (13)	<.0001
Atrial fibrillation	984	96 (9.8)	1918	246 (13)	.02
NYHA functional class	1029		2051		.3
I		380 (37)		781 (38)	
II		519 (50)		1047 (51)	
III		111 (11)		199 (9.7)	
IV		19 (1.8)		24 (1.2)	
Noncardiac comorbidity					
Hypertension	1014	582 (57)	1989	823 (41)	<.0001
COPD	1013	43 (4.2)	1989	132 (6.6)	.008
Diabetes					
Insulin-treated	1021	5 (0.49)	2034	8 (0.39)	.8
Noninsulin-treated	1021	46 (4.5)	2034	43 (2.1)	.0002
Creatinine (mg/dL)	1005	1.0 $\pm$ 0.41	1966	1.0 $\pm$ 0.48	<.0001
Pathophysiology					
Regurgitation grade	1003		1976		<.0001
Moderate		4 (0.40)		33 (1.7)	
Moderate to severe		70 (7.0)		323 (16)	
Severe		929 (93)		1620 (82)	
Leaflet cleft	948	28 (3.0)	1936	65 (3.4)	.6
Chordal rupture	948	909 (96)	1936	1316 (68)	<.0001
Chordal elongation	948	140 (15)	1936	474 (24)	<.0001
Leaflet calcification	948	4 (0.42)	1936	36 (1.9)	.001
Repair technique					
Annuloplasty	1036	1025 (99)	2065	2030 (98)	.17
Leaflet resection	1036	954 (92)	2065	1849 (90)	.02
Sliding repair	1036	396 (38)	2065	803 (39)	.7
Artificial chordae	1036	62 (6.0)	2065	118 (5.7)	.8
Chordal transfer	1036	15 (1.4)	2065	44 (2.1)	.19
Commissuroplasty	1036	26 (2.5)	2065	50 (2.4)	.9
Complication					
Death	1036	0 (0)	2065	1 (0.048)	>.9
Respiratory complication	768	13 (1.7)	1383	19 (1.4)	.6
Sternal wound infection	1036	7 (0.68)	2065	5 (0.24)	.12
Reoperation for bleeding	1036	23 (2.2)	2065	45 (2.2)	.9
Atrial fibrillation	906	311 (34)	1724	491 (28)	.002
Renal failure	901	1 (0.11)	1729	1 (0.058)	>.9
Stroke	1036	12 (1.2)	2065	18 (0.087)	.4

LV, Left ventricle; LVESVI, left ventricular end-systolic volume index; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. *Patients with data available.

TABLE E7. Complex degenerative mitral valve disease: Unmatched versus propensity matched

Characteristic	Complex disease unmatched (n = 987)		Complex disease matched (n = 2065)		P value
	n*	n (%) or mean $\pm$ standard deviation	n*	n (%) or mean $\pm$ standard deviation	
Demographic					
Age (y)	987	53 $\pm$ 14	2065	57 $\pm$ 12	<.0001
Female	987	564 (57)	2065	596 (29)	<.0001
Cardiac comorbidity					
LV ejection fraction (%)	791	57 $\pm$ 6.5	1860	58 $\pm$ 6.6	<.0001
LVESVI (mL/m)	640	25 $\pm$ 12	1522	24 $\pm$ 11	.12
LV mass index (g/m)	637	125 $\pm$ 33	1520	129 $\pm$ 36	.08
Heart failure	987	122 (12)	2065	293 (14)	.17
Atrial fibrillation	911	189 (21)	1931	247 (13)	<.0001
NYHA functional class	983		2058		.3
I		339 (34)		782 (38)	
II		515 (52)		1029 (50)	
III		118 (12)		225 (11)	
IV		11 (1.1)		22 (1.1)	
Noncardiac comorbidity					
Hypertension	914	243 (27)	1970	825 (42)	<.0001
COPD	914	69 (7.5)	1970	107 (5.4)	.03
Diabetes					
Insulin-treated	973	2 (0.21)	2024	7 (0.35)	.7
Noninsulin-treated	973	9 (0.92)	2024	41 (2.0)	.03
Creatinine (mg/dL)	898	0.96 $\pm$ 0.75	1944	0.99 $\pm$ 0.46	<.0001
Pathophysiology					
Regurgitation grade	891		1958		<.0001
Moderate		63 (7.1)		26 (1.3)	
Moderate to severe		367 (41)		342 (17)	
Severe		461 (52)		1590 (81)	
Leaflet cleft	940	38 (4.0)	1936	73 (3.8)	.7
Chordal rupture	940	177 (19)	1936	1344 (69)	<.0001
Chordal elongation	940	379 (40)	1936	470 (24)	<.0001
Leaflet calcification	940	32 (3.4)	1936	31 (1.6)	.002
Repair techniques					
Annuloplasty	987	973 (99)	2065	2027 (98)	.4
Leaflet resection	987	678 (69)	2065	1571 (76)	.0001
Sliding repair	987	443 (45)	2065	934 (45)	.9
Artificial chordae	987	116 (12)	2065	283 (14)	.13
Chordal transfer	987	163 (17)	2065	307 (15)	.2
Commissuroplasty	987	59 (6.0)	2065	119 (5.8)	.8
Complication					
Death	987	1 (0.10)	2065	2 (0.10)	>.9
Respiratory complication	602	14 (2.3)	1443	34 (2.4)	>.9
Sternal wound infection	987	3 (0.30)	2065	7 (0.34)	>.9
Reoperation for bleeding	987	33 (3.3)	2065	56 (2.7)	.3
Atrial fibrillation	738	192 (26)	1717	491 (29)	.19
Renal failure	739	2 (0.27)	1749	3 (0.17)	.6
Stroke	987	9 (0.91)	2065	28 (1.4)	.3

LV, Left ventricle; LVESVI, left ventricular end-systolic volume index; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. *Patients with data available.

TABLE E8. Incremental risk factors for progression of mitral valve regurgitation (n = 6153)

Factor	Coefficient $\pm$ standard error	P value	Reliability (%) [*]
Early phase			
Black race	0.94 $\pm$ 0.37	.01	77
Prior myocardial infarction	0.86 $\pm$ 0.32	.006	97
Lower preoperative creatinine clearance (Cockcroft-Gault) [†]	−0.80 $\pm$ 0.21	.0002	78
Higher preoperative RV systolic pressure [‡]	0.75 $\pm$ 0.22	.001	100
Higher preoperative unscaled LA volume index [‡]	0.58 $\pm$ 0.15	.0002	88
Complex prolapse	0.12 $\pm$ 0.14	.4	100
Placement of artificial chordae	1.5 $\pm$ 0.19	<.0001	100
Earlier date of operation [‡]	−1.8 $\pm$ 0.15	<.0001	100
Late phase			
Complex prolapse	4.6 $\pm$ 0.55	<.0001	100
No leaflet resection	−3.0 $\pm$ 1.2	.004	97

RV, Right ventricle; LA, left atrium. ^{*}Percent of times factor appeared in 1000 bootstrap models. [†]Creatinine clearance/90, scaled transformation. [‡]Natural logarithmic transformation.

TABLE E9. Incremental risk factors for reoperation (n = 6153)

Factor	Coefficient $\pm$ standard error	P value	Reliability (%) [*]
Early phase			
Complex prolapse	0.70 $\pm$ 0.25	.004	69
Higher preoperative NYHA class	0.35 $\pm$ 0.15	.02	52
Preoperative unscaled LA volume index [†]	0.45 $\pm$ 0.22	.04	66
Higher preoperative creatinine clearance (Cockcroft-Gault) [‡]	0.60 $\pm$ 0.20	.003	86
Lower preoperative hematocrit [§]	−2.7 $\pm$ 0.93	.004	66
Earlier date of operation	−0.39 $\pm$ 0.15	.01	79
Placement of artificial chordae	0.78 $\pm$ 0.39	.05	89
Late phase			
Complex prolapse	0.78 $\pm$ 0.31	.01	83
Prior myocardial infarction	1.4 $\pm$ 0.41	.0009	72
Preoperative pulmonary valve regurgitation	1.3 $\pm$ 0.30	<.0001	87
No history of smoking	−0.76 $\pm$ 0.32	.02	58
Higher preoperative BUN [¶]	0.84 $\pm$ 0.36	.02	60
Annuloplasty	−2.1 $\pm$ 0.32	<.0001	96
No leaflet resection	−1.2 $\pm$ 0.31	.0002	56

NYHA, New York Heart Association; LA, left atrium; BUN, blood urea nitrogen. ^{*}Percent of times factor appeared in 1000 bootstrap models. [†]Natural logarithmic transformation. [‡]Creatinine clearance/100, scaled transformation. [§]Hematocrit/40, scaled transformation. ^{||}Ln(interval from January 1, 1985 to index operation), natural logarithmic transformation. [¶]BUN/20, scaled transformation.

TABLE E10. Incremental risk factors for death (n = 6153)

Factor	Coefficient $\pm$ standard error	P value	Reliability (%) [*]
Constant phase			
Complex prolapse	0.058 $\pm$ 0.13	.6	19
Older age [†]	1.2 $\pm$ 0.073	<.0001	100
Lower LV ejection fraction [‡]	−0.99 $\pm$ 0.39	.01	91
Heart failure	0.28 $\pm$ 0.12	.02	78
Prior stroke	0.67 $\pm$ 0.20	.0009	68
Higher preoperative BUN	0.018 $\pm$ 0.0087	.04	95
Earlier date of operation	−0.046 $\pm$ 0.0092	<.0001	90
Late phase			
Complex prolapse	−0.15 $\pm$ 0.21	.5	14
Higher preoperative body mass index [‡]	2.2 $\pm$ 0.62	.0003	68
Prior myocardial infarction	1.0 $\pm$ 0.28	.0004	67
Higher preoperative tricuspid valve regurgitation grade	0.42 $\pm$ 0.11	.0002	60
Preoperative pulmonary valve regurgitation	0.85 $\pm$ 0.21	<.0001	72
Carotid disease	1.0 $\pm$ 0.36	.005	64
Lower preoperative creatinine clearance (Cockcroft-Gault)	−0.026 $\pm$ 0.0036	<.0001	51

LV, Left ventricle; BUN, blood urea nitrogen. ^{*}Percent of times factor appeared in 1000 bootstrap models. [†]Exponential transformation. [‡]Natural logarithmic transformation.