Ischemic mitral valve reconstruction and replacement: Comparison of long-term survival and complications

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Objective: This study reviews the 223 consecutive mitral valve operations for ischemic mitral insufficiency performed at New York University Medical Center between January 1976 and January 1996. The results for mitral valve reconstruction are compared with those for prosthetic mitral valve replacement.

Methods: From January 1976 to January 1996, 223 patients with ischemic mitral insufficiency underwent mitral valve reconstruction (n = 152) or prosthetic mitral valve replacement (n = 71). Coronary artery bypass grafting was performed in 89% of cases of mitral reconstruction and 80% of cases of prosthetic replacement. In the group undergoing reconstruction, 77% had valvuloplasty with a ring annuloplasty and 23% had valvuloplasty with suture annuloplasty. In the group undergoing prosthetic replacement, 82% of patients received bioprostheses and 18% received mechanical prostheses.

Results: Follow-up was 93% complete (median 14.6 mo, range 0-219 mo). Thirty-day mortality was 10% for mitral reconstruction and 20% for prosthetic replacement. The short-term mortality was higher among patients in New York Heart Association functional class IV than among those in classes I to III (odds ratio 5.75, confidence interval 1.25-26.5) and was reduced among patients with angina relative to those without angina (odds ratio 0.26, confidence interval 0.05-1.2). The 30-day death or complication rate was similarly elevated among patients in functional class IV (odds ratio 5.53; confidence interval 1.23-25.04). Patients with mitral valve reconstruction had lower short-term complication or death rates than did patients with prosthetic valve replacement (odds ratio 0.43, confidence interval 0.20-0.90). Eighty-two percent of patients with mitral valve reconstruction had no insufficiency or only trace insufficiency during the long-term follow-up period. Five-year complication-free survivals were 64% (confidence interval 54%-74%) for patients undergoing mitral valve reconstruction and 47% (confidence interval 33%-60%) for patients undergoing prosthetic valve replacement. Results of a series of statistical analyses suggest that outcome was linked primarily to preoperative New York Heart Association functional class.

Conclusions: Initial mortalities were similar among patients undergoing prosthetic replacement and valve reconstruction. Poor outcome was primarily related to preexisting comorbidities. Patients undergoing valve reconstruction had fewer valve-related complications. Valve reconstruction resulted in excellent durability and freedom from complications. These findings suggest that mitral valve reconstruction should be considered for appropriate patients with ischemic mitral insufficiency.

Mitral insufficiency caused by coronary ischemia has various clinical presentations, ranging from cardiogenic shock related to acute papillary muscle rupture to chronic congestive heart failure related to ventricular dysfunction with annular dilation. Reported perioperative mortality for mitral reconstruction in these patients ranges widely, from 9%¹ to 18%,² although the variety of patient subtypes makes it difficult to analyze the impact of mitral valve reconstructive techniques in reports on small patient groups. Although mitral reconstruction demonstrably provides better preservation of ventricular function³ than does mitral replacement without chordae-sparing procedures and produces superior freedom from valve-related complications⁴ in patients with degenerative mitral insufficiency, similar advantages have not yet been definitely demonstrated for the subset of patients with ischemic mitral insufficiency. Kay and colleagues⁵ demonstrated good results with mitral repair for patients with ischemic mitral insufficiency, but no analyses were performed to examine the impact of confounding variables. A study by Cohn and associates⁶ reported that mitral reconstruction in patients with ischemic mitral insufficiency was associated with a 5-year mortality 5 times higher than that seen after replacement. Confounding variables, such as acuity of presentation, degree of global ventricular dysfunction, and the specific pathophysiologic characteristics of the ischemic mitral insufficiency, certainly influenced these outcomes. A large experience with long follow-up is required to resolve these issues and to provide a valid comparison between mitral valve reconstruction and valve replacement for patients with ischemic mitral insufficiency. This study reviews New York University Medical Center's 19-year experience with operations for ischemic mitral insufficiency.

Methods

Variable Definitions

Ischemic mitral insufficiency was considered to be the presence of severe mitral incompetence (according to either echocardiographic or angiographic criteria) arising from an ischemic process confirmed by the intra-operative pathologic evaluation of the valve. Patients with other causes for the mitral insufficiency (degenerative, rheumatic, infective, or congenital) were excluded from this analysis. Mitral insufficiency was considered acute if the onset of symp-

toms was less than 1 month before the operation or was associated with an acute myocardial infarction during the same hospitalization.

A modification of the pathophysiologic classifications proposed by Rankin and colleagues,⁷ Carpentier,⁸ and Cohn and associates⁶ was used. The mitral insufficiency cases were classified into three largely exclusive categories. Annular dilation was characterized as intact leaflets, chordae, and papillary muscles in association with a dilated anulus (type 1). Structural mitral insufficiency was characterized by the presence of ruptured or elongated papillary muscles (type 2). Ventricular-papillary dysfunction consisted of ischemic or infarcted nonruptured papillary muscles in association with normal chordae and intact anulus and leaflets (type 3).

Patient Population

From January 1976 through January 1996, a total of 223 consecutive patients at our institution underwent isolated mitral valve surgery for severe mitral insufficiency of ischemic origin. Mitral insufficiency was measured by either preoperative ventriculography or echocardiography; in the latter half of this series intraoperative transesophageal echocardiography was routinely used. The mitral operations included 152 reconstructions (77% Carpentier technique⁴ with ring annuloplasty and 23% suture annuloplasty) and 71 mitral valve replacements (82% with bioprostheses and 18% with mechanical prostheses). Moderate systemic hypothermia and cold blood cardioplegia were used throughout the series, with retrograde cardioplegic delivery used extensively in the last decade. The patients undergoing mitral replacement had preservation of the posterior leaflet whenever possible. Mitral replacement was preferred for patients with significant disruption or necrosis of the papillary muscle and with ventricular-papillary muscle dysfunction. Annular dilation was preferentially treated with mitral reconstruction.

The mean age for all the patients in the study was 67.9 ± 8.8 years, and 86% of the patients underwent concomitant coronary artery bypass grafting. Those patients who did not undergo concomitant coronary artery bypass grafting typically had either acute papillary muscle rupture in association with a completed transmural infarction or chronic mitral insufficiency with coronary disease that could not be ameliorated by coronary artery bypass grafting. Indices of preoperative risk included preoperative use of an intra-aortic balloon pump in 7% of the cases, preoperative intubation in 13%, and cardiogenic shock in 5%. Ventricular function was impaired in most patients (54%).

After the operation all patients received coumadin for the first 3 months if tolerated. After that, patients with a mechanical valve, chronic atrial fibrillation, or history of thromboembolic events continued to receive coumadin indefinitely.

Figure 1. Follow-up after surgery according to type of surgery.

Operative information and patient demographic characteristics for mitral valve patients are routinely collected at our institution and are maintained in a database. The standard terminology for reporting valvular surgery outcomes, such as hospital mortality, was used throughout.⁹ Patients were followed up for complications and deaths from all causes. Deaths from all causes are reported here, but late death (death from any cause of a patient who survived ≥ 30 days after surgery) was also examined. Late cardiac death (including valve-related deaths, sudden unexplained deaths and deaths due to congestive heart failure, acute myocardial infarction, and documented fatal arrhythmias) was the cause of all but one of these late deaths. All patients who underwent mitral valve reconstruction were requested to undergo echocardiographic assessment of the mitral valve at 6 months and at 1 year after the operation and then once a year after the first year. The results of the most recent echocardiographic assessment were obtained at follow-up contact. For the follow-up study, clinical research nurses contacted the patients, their families, or their physicians once each year. Follow-up was obtained in 97% of cases; searches made with the social security numbers of those patients who were unavailable for follow-up suggested that they were still alive, although they could not be contacted. A total of 550 patient-years of follow-up was reviewed in this report (mean 30.8 months, median 14.6 months, range 0-219 months). Figure 1 shows the distribution of follow-up times according to type of surgery.

Statistical Methods

The case series described is observational, and it is recognized that the choice of surgical procedure may be biased by physician preference and patient characteristics. To examine these issues, multiple exploratory analyses were undertaken. The strategy is described here.

Characteristics were compared at baseline (time of surgery) for patients who underwent valve replacement and valve repair procedures. To screen for baseline differences between the two groups of patients, distributions of characteristics at surgery were compared with 2-sided *t* tests for the continuous variables such as age and with χ^2 tests or Fisher exact tests for the categorical variables. Because the *P* values were used only as a screening tool, no adjustments for multiplicity were made.

Differences between the operative groups at the time of surgery were then examined with methods of linear discriminant analysis and multiple logistic regression. Variables selected for inclusion in these analyses included the variables judged from the univariate analyses to be potentially different between the two groups and also included other variables that may play an important role in the choice of procedure to be performed. All subjects with complete data on all candidate variables were included in the models. Model diagnostics and goodness of fit tests (Hosmer-Lemeshow C statistics for the logistic models and The Hotelling T square for the linear discriminant models) were performed.

Thirty-day mortalities in the repair and replacement groups were also compared with multiple logistic regression models. Models were selected with procedures similar to those described previously to compare the two groups of patients at the time of surgery.

Time-to-failure curves were compared with log-rank tests for (1) total mortality (death) and (2) first complication or death across the entire follow-up period. Cox proportional hazard models were also developed to compare the patients in the two groups with adjustments for variables that were (1) selected from the analyses of the baseline characteristics as sources of possible differences between the repair and replacement groups, and (2) considered a priori to be important in the choice of surgery or prognosis. Model diagnostics and likelihood ratio tests for goodness of fit were performed. Hazard ratios and 95% confidence intervals (CIs) were estimated from these models. Time-to-failure models were also developed for the repair and replacement groups separately to explore the effects of patient selection on the results of the comparisons between the two groups of patients.

To assess the potential impact on model development of the use of cases with complete data, Kaplan-Meier survival curves were compared for patients with and without complete data in the repair and replacement groups separately.

Supplementary analyses with propensity score methods¹⁰ were also applied to aid in the understanding of the impact of covariates on outcome in these two selected groups of patients. All analyses were carried out with SAS V.8.0 (SAS Institute, Inc, Cary, NC) and S Plus 2000 software packages.

Results

Baseline Characteristics and Outcomes

Baseline characteristics. Two hundred twenty-three consecutive patients underwent surgery with either mitral valve repair ($n = 152$) or replacement ($n = 71$) at New York University Medical Center between 1976 and 1996. Table 1A provides a summary of the characteristics of these patients at the time of operation. The average age of these patients was 68 years. Although the groups were comparable in many respects, the proportion of the patients in New York Heart Association (NYHA) functional class IV was greater among the patients undergoing replacement (79%) than among those undergoing repair (59%). Ninety-two percent of patients in the repair group had angina, and 96% of the patients in the replacement group had congestive heart failure. The distributions of time of surgery (year) were also markedly different in the two groups of patients (Figure 1). In fact, few repairs were conducted in patients with ischemic mitral insufficiency before 1988. We therefore examined this cohort effect (before 1988 vs 1988 or later) by separately performing all the multivariable analyses reported here on patients operated on in the latter half of our series; Table 1B provides a comparison of the two groups after 1988. Table 2 provides a summary of the mortality and complication outcomes according to type that are included in the subsequent analyses of mortality and complication-free survival.

The choice of operative procedure depended on the characteristics of the patient at presentation. The distributions of pathophysiologic subtypes according to type of surgery are summarized in Tables 1A and 1B. Note that 17% of the patients in the repair group had acute regurgitation, compared with 29% of those in the replacement group, and 67% of the patients in the repair group had isolated annular dilation, compared with only 34% in the replacement group.

Linear discriminant analysis and multiple logistic regression analyses were carried out to explore the differences between the two operative groups. The following variables were included in the various exploratory analyses: surgery before or after 1988, acuity of mitral insufficiency, annular dilation, structural failure such as ruptured papillary muscle, ventricular papillary muscle dysfunction, congestive heart failure, NYHA functional class, gender, concomitant coronary artery bypass grafting, previous cardiac surgery, emergency operation, angina, diabetes, and age. The most important variable found from these models was the year of surgery (1988 or later vs before 1988). Tables 3A and 3B summarize the results of the models resulting from each of these two approaches. Only NYHA functional class and the presence of annular dilation were significant in the multivariable analyses. Furthermore, in all the exploratory models the predicted classification was poor (<20% correct). Goodness of fit was assessed with the Hosmer-Lemeshow C statistics for the logistic models and the Hotelling T square for the linear discriminant models.

Logistic regression models that included all covariates were also used to attempt to develop propensity scores for repair versus replacement. Forty percent of the patients in the replacement group were in the lowest quintile of propensity score, as opposed to only 4% of the patients in the repair group, and 10% of the patients in the replacement group were in the highest quintile of propensity score, as opposed to 68% of repair patients. Quintile II consisted entirely of patients treated before 1988. The propensity score models did not provide an adequate fit to the data within quintiles of risk (Hosmer-Lemeshow C statistic, χ^2 (8 df) = 18.33, $P = .0189$). When the choice of operative procedure is confounded with respect to disease characteristics, it is not unexpected that no balance can be achieved through the use of propensity scores.¹⁰⁻¹² Propensity scores were therefore not used to carry out adjustments in the subsequent analyses reported here.

Table 4 illustrates the nature of the confounding among NYHA functional classification and the presence or absence of angina and choice of repair or replacement procedure. Thirty-six percent of the patients in the repair group were in NYHA functional classes I through III with angina, compared with 18% of those in the replacement group. Only 2% of the patients in the repair group were in functional class IV without angina, compared with 20% of those in the replacement group.

TABLE 1A. Comparison of patient characteristics (for all patients)

		Mitral repair (N = 152, 68%)		Mitral replacement (N = 71, 32%)		
Total cases (N = 223)		No.	%	No.	%	P value*
Patient characteristics						
Age	222	151†	68	71‡	32	.92§
Missing		1				
Gender	222	151		71		.53
Male		96	64	42	59	
Female		55	36	29	41	
Missing		1				
Preoperative NYHA functional class	222	152		70		.02¶
I		1	0.7	0		
II		7	4.6	2	2.9	
III		55	36.2	13	18.6	
IV		89	58.6	55	78.6	
Missing				1		
Concomitant coronary artery bypass grafting	223		152	71		.09
Yes		135	89	57	80	
No		17	11	14	20	
Previous cardiac surgery		223	152	71		.97
Yes		19	12	9	13	
No		133	88	62	87	
Emergency operation	223	152		71		.72
Yes		42	28	18	25	
No		110	72	53	75	
Preoperative angina	209		152	57		.001
Yes		140	92	43	75	
No		12	8	14	25	
Missing				14		
Diabetes	223		152	71		.91
Yes		46	30	22	31	
No		106	70	49	69	
Preoperative ejection fraction	127	110		17		.94¶
≤20		38	35	6	35	
>20-30		22	20	4	24	
>30		50	45	7	41	
Missing		42		54		
Congestive heart failure	221		150		71	.05
Yes		131	87	68	96	
No		19	13	3	4	
Missing		2				
Pathophysiologic subtypes						
Mitral regurgitation	213	150		63		.05
Acute		25	17	18	29	
Chronic		125	83	45	71	
Missing		2		8		
Pathophysiology	223		152	71		<.0001
Isolated annular		102	67	24	34	
Structural		34	22	24	34	
Papillary muscle dysfunction		16	11	23	32	
Operative characteristics						
Aortic occlusion time	182	134**	74	48††	26	<.0001§
Missing		18		23		
Bypass time	183	134‡‡	73	49§§	27	.0013§
Missing		18		22		
Type of operation	221		150	71		.33¶
Elective		95	63	44	62	
Emergency		36	24	18	25	
Reoperation		13	9	9	13	
Emergency reoperation		6	4	0	0	
Missing		2				

*All tests are 2-sided. Missing values were not included in the calculations.

†Mean, 67.98 years.

‡Mean, 67.85 years.

§By t test.

|| By χ^2 test.

¶By Fisher exact test.

**Mean 59.8 minutes.

††Mean 104.77 minutes.

‡‡Mean 144 minutes.

§§Mean 177 minutes.

TABLE 1B. Comparison of patient characteristics after 1988

	Total cases (N = 160)	Mitral repair (N = 127, 79.38%)		Mitral replacement (N = 33, 20.62%)		P value*
		No.	%	No.	%	
Patient characteristics						
Age	159	126†	79	33‡	21	.89§
Missing		1				
Gender	159	126		33		.53
Male		80	64	19	58	
Female		46	36	14	42	
Missing		1				
Preoperative NYHA functional class	159	127		32		.04¶
I		0		0		
II		5	4	1	3	
III		44	35	4	13	
IV		78	61	27	84	
Missing		1				
Concomitant coronary artery bypass grafting	160	127		33		.13
Yes		110	87	25	76	
No		17	13	8	24	
Previous cardiac surgery	160	127		33	27	.07
Yes		18	14	9		
No		109	86	24	73	
Emergency operation	160	127		33		.70
Yes		39	31	9	27	
No		88	69	24	73	
Preoperative angina	149	127		22		.04¶
Yes		121	95	18	82	
No		6	5	4	18	
Missing				11		
Diabetes	160	127		33		.05
Yes		42	33	13	39	
No		85	67	20	61	
Preoperative ejection fraction	122	106		16		.88
≤20		38	36	5	31	
>20-30		21	20	4	25	
>30		47	44	7	44	
Missing		21		17		
Congestive heart failure	159	126		33		.07¶
Yes		113	90	33	100	
No		13	10	0	0	
Missing		1				
Pathophysiologic subtypes						
Mitral regurgitation	158	125		33		.05
Acute		22	18	11	33	
Chronic		103	82	22	67	
Missing		2				
Pathophysiology	160	127		33		<.001
Isolated annular dilation		90	71	11	33	
Structural		26	20	14	43	
Papillary muscle dysfunction		11	9	8	24	
Operative characteristics						
Aortic occlusion time	149	118**	79	31††	21	<.001§
Missing		9		2		
Bypass time	150	118‡‡	78.8	32§§	21.3	.015§
missing		9		1		
Type of operation	158	125		33		.05¶
Elective		74	59	15	45	
Emergency		33	26	9	27	
Reoperation		12	10	9	27	
Emergency reoperation		6	5	0	0	
Missing		2				

*All tests are 2-sided. Missing values were not included in the calculations.

†Mean 68.75 years.

‡Mean 68.94 years.

**Mean 54.39 minutes.

††Mean 115.19 minutes.

‡‡Mean 141.1 minutes.

§§Mean 183.66 minutes.

TABLE 2. Patient outcomes by type of surgery and time of surgery

	All patients (N = 223)	Mitral repair				Mitral replacement			
		Total (N = 152)		During and after 1988 (N = 127)		Total (N = 71)		During and after 1988 (N = 33)	
		No.	%	No.	%	No.	%	No.	%
Complications									
Thromboembolic	9	3	2	1	0.8	6	8	0	0
Anticoagulation	5	1	0.7	0	0	4	6	2	6
Endocarditis	2	0	0	0	0	2	3	1	3
Death									
Any death	72	41	27	30	24	31	44	13	39
Within 30 d	29	15	10	12	10	14	20	18	24
After 30 d	43	26	17	18	14	17	24	5	15
In hospital	38	23	15	18	14	15	21	9	27
In hospital within 30 d	29	15	10	12	10	14	20	8	15
Complications or death									
Any complication	82	45	30	31	24	37	52	15	45
Within 30 d	31	15	10	12	10	16	22	9	27
After 30 d	51	30	20	19	14	21	30	6	18

Outcome: 30-day mortality and complication-free survival. Thirty-day mortality and complications or death within 30 days were examined with logistic regression analysis (Tables 5A and 5B). The results, shown in Table 5A, suggest that the odds of death within 30 days after surgery for all patients and for patients operated on in 1988 or later were markedly elevated for patients in NYHA functional class IV relative to patients in classes I through III (9.6 times greater and 5.8 times greater, respectively). Results were similar for death or complication within 30 days of surgery. No other variable, including type of operative procedure, contributed significantly to the prediction of the odds of death within 30 days.

Because of the high degree of confounding of type of surgery with the presence of angina and NYHA functional class at baseline, logistic models were also fitted excluding angina and NYHA functional class. Table 5B provides the results of these analyses, which suggest that the odds of death within 30 days after surgery or complication or death within 30 days after surgery were significantly lower for patients with repair than for patients with replacement. This result supports the observation that the selection of patients for type of surgery is confounded with NYHA functional class and the presence of angina, and the lowered risk for patients in the repair group may have been due to the selection criteria for the surgery rather than to the surgical procedure.

Outcome: Survival and complication-free survival. Survival for all patients in the cohort is shown in Figure 2, A; survival for patients operated on in 1988 or later is shown in Figure 2, B. The risk of death for the repair group relative to the replacement group was 0.75 (95% CI 0.463-1.202)

for all patients and was 0.66 (95% CI 0.338-1.302) for patients entered in 1988 or later. Appendix Tables 1A and 2A provide survival rates for 5 years from surgery for all patients and for patients entered in 1988 or later.

Figure 3, A and B, provides similar curves for complication-free survival. The risk of complication or death for repair relative to replacement was 0.63 (95% CI 0.405-0.980) for all patients and 0.50 (95% CI 0.267-0.952) for patients operated on in 1988 or later. Appendix Tables 1B and 2B provide the complication-free survival rates for 5 years after surgery. For the group of patients with surgery in 1988 or later who could have received either operation, there was a possible advantage to repair rather than replacement according to the unadjusted hazard ratios. Adjustments were therefore explored.

Outcome: Survival and complication-free survival for patients surviving complication free for 30 days. Figure 4, A and B, provides survival curves for all patients and for all patients operated on in 1988 or later who survived free of complications for 30 days after surgery. Figure 5, A and B, provides the complication-free survival for the same groups of patients. The curves for survival and for complication-free survival conditional on complication-free survival for 30 days after surgery were similar for both types of surgery in the early years after surgery. The hazard ratios and 95% CI for survival and complication-free survival for patients who survived free of complications for 30 days or longer are provided in Table 6. Although the hazard ratios for repair versus replacement were consistently below unity, the 95% CIs were wide.

Outcome: Postdischarge survival and complication-free survival. We also examined the outcomes of the 150 patients

Figure 2. Survival according to type of operation. A, All patients; B, patients operated on in 1988 or later. Filled diamonds represent replacement; open circles represent repair.

who were discharged from the hospital. We defined survival time as the interval from the date of the discharge to the date of death. The risk of death for repair relative to replacement was 0.98 (95% CI 0.36-2.66), and the risk of complication or death was 0.95 (95% CI 0.38-2.36). For patients operated on in 1988 or later, the risk of death was 0.87, 95% CI (0.27, 2.74) and the

risk of complication or death is 0.71 with 95% CI (0.25, 2.04). Thus for those patients who were discharged from the hospital the outcomes were similar regardless of type of surgery.

The risk of death in the hospital for repair relative to replacement was 0.98 (95% CI 0.5-1.97), and the risk of complication or death was 0.81 (95% CI 0.43-1.56). For

TABLE 3A. Multivariate comparison of valve replacement and valve repair groups: Multiple logistic regression method (response variable, type of valve procedure)

	Repair group	Replacement group	Model, variables included	Odds ratio	95% CI	Goodness of fit (Hosmer-Lemeshow test)
All patients	152	70	NYHA functional class (IV vs ≤III)	0.26	0.12-0.57	$\chi^2_6 = 0.67, P = .637$
			After 1988 (vs earlier)	6.27	3.08-12.73	
			Isolated annular dilation (vs not)	3.25	1.81-6.84	
Patients entered 1988 or later	127	22	Preoperative angina (vs none)	4.96	1.13-21.79	$\chi^2_2 = 0.67, P = .720$
			Isolated annular dilation (vs not)	5.41	1.99-14.72	

Variables included: NYHA functional class, type of valve procedure, preoperative angina, previous cardiac surgery, type of mitral regurgitation, congestive heart failure, concomitant coronary artery bypass grafting, diabetes, gender, age, anulus, entry after 1988, and the need for reoperation.

TABLE 3B. Multivariate comparison of valve replacement and valve repair groups: Linear discriminant analysis method² (dependent variable, type of valve procedure)

	Variables	Estimated coefficient	95% CI	Hotelling T square
All patients	Isolated annular dilation (vs not)	−0.3	−0.53 to −0.08	$F(12,183) = 5.64, P < .001$
	After 1988 (vs earlier)	−0.4	−0.6 to −0.2	
Patients entered 1988 or later	Isolated annular dilation (vs not)	0.37	0.043 to 0.697	$F(11,132) = 2.9, P = .002$

Variables included: NYHA functional class, type of valve procedure, preoperative angina, structural failure, previous cardiac surgery, type of mitral regurgitation, congestive heart failure, concomitant coronary artery bypass grafting, diabetes, gender, age, isolated annular dilation, and the need for reoperation.

patients entered in 1988 or later, the risk of death and the risk of complication or death were 0.72 (95% CI 0.32-1.6) and 0.63 (95% CI 0.29-1.35).

Outcomes according to characteristics at time of surgery (patients entered in 1988 or later). Table 7 shows the hazard ratios for death and for complication or death for patients who received mitral repairs relative to those who received valve replacements in 1988 or later within subgroups defined by levels of baseline variables. Although the numbers of patients in each subgroup were small, the results suggest that within most of these subgroups patients with repair had a lower risk of death or complication or death than did patients with replacement (although most of the CIs on the hazard ratios included unity). Patients older than 70 years had markedly lower risks with repair, as did patients without concomitant coronary artery bypass grafting, patients with emergency surgery, and patients with isolated annular dilation.

Cox proportional hazards models were also used to adjust for covariates in the comparison of survivals between repair and replacement groups operated on in 1988 or later. Because of the confounding of baseline covariates with patient selection, Cox models were also developed without angina and NYHA functional class, the variables that appeared to be associated with patient selection groups separately. Variables included were those discerned from the

TABLE 4. Distribution of patients with repair and replacement according to NYHA functional class and presence of angina

NYHA functional class	Angina	Mitral repair		Mitral replacement	
		No.	%	No.	%
I, II, or III	No	9	5.9	3	5.53
I, II, or III	Yes	54	35.5	10	17.9
IV	No	3	1.97	11	19.6
IV	Yes	86	56.58	32	57.1
TOTAL		152	56		

baseline comparisons and those discovered in the earlier analyses to be confounded with type of surgery.

Tables 8A and 8B present the results of the model for the comparison of repair and replacement groups. In Table 8A all variables are included for model selection in addition to the type of surgery. The variables included in the final models are provided, along with the associated adjusted hazard ratios and 95% CIs and the test of model fit. Patients in NYHA functional class IV had a markedly increased adjusted risk or complication in all the patient subsets.

Other characteristics of patients at the time of surgery also contributed to modification of the risks, although the particular characteristics varied with the patient subset. In no instance did the type of surgery emerge as an additional independent variable that contributed to outcome.

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TABLE 5A. Odds ratios for death within 30 postoperative days and for complications or death within 30 postoperative days: Multiple logistic regression

Patient subsets	Model variables included	Odds ratio	95% CI	Hosmer-Lemeshow test
30-d mortality				
All patients	NYHA functional class (IV vs ≤III)	9.58	2.2-41.3	$\chi^2_2 = 0.62$
	Valve procedure (repair vs replacement)	0.65	0.3-1.45	$P = .73$
Patients entered 1988 or later	Preoperative angina (yes vs no)	0.26	0.05-1.2	$\chi^2_2 = 0.65$
	NYHA functional class (IV vs ≤III)	5.75	1.25-26.5	$P = .42$
Complications or death within 30 d				
All patients	NYHA functional class (IV vs ≤III)	9.36	2.2-40.5	$\chi^2_2 = 0.42$
	Valve procedure (repair vs replacement)	0.54	0.25-1.19	$P = .81$
Patients entered 1988 or later	Valve procedure (repair vs replacement)	0.43	0.2-0.9	$\chi^2_2 = 1.38$
	NYHA functional class (IV vs ≤III)	5.53	1.23-25.04	$P = 0.81$

TABLE 5B. Odds ratios for death within 30 postoperative days and for complications or death within 30 postoperative days: Multiple logistic regression excluding NYHA functional class and angina from covariables

Patient subsets	Model variables included	Odds ratio	95% CI	Hosmer-Lemeshow test
30-d mortality				
All patients	Isolated annular dilation (yes vs no)	1.99	0.85-4.67	$\chi^2_2 = 4.57$
	Valve procedure (repair vs replacement)	0.4	0.18-0.93	$P = .1$
Patients entered 1988 or later	Valve procedure (repair vs replacement)	0.34	0.12-0.96	$\chi^2_2 = 3.82$
	Isolated annular dilation (yes vs no)	0.15	0.52-4.1	$P = .15$
Complications or death within 30 d				
All patients	Diabetes (yes vs no)	1.87	0.87-4.0	$\chi^2_2 = 0.06$
	Valve procedure (repair vs replacement)	0.43	0.2-0.9	$P = .97$
Patients entered 1988 or later	Valve procedure (repair vs replacement)	0.34	0.13-0.89	$\chi^2_2 = 0.137$
	Diabetes (yes vs no)	2.3	0.93-5.76	$P = .99$

45% to 61% the adjusted risk of death of those in the replacement group and 55% to 61% the adjusted risk of complication or death in the presence of the covariates included. These results confirm the selection process associated with the choice of surgery for these patients.

Because of the patient selection inherent in the choice of surgical procedure and the confounding of baseline characteristics at time of surgery with the choice of procedure, we also developed Cox models for each of the two surgical cohorts separately. Table 9 provides the results of the Cox models for each of the groups. Among all patients in the repair group the relative risk of death or any event was 3 times greater for patients in NYHA functional class IV than for those in classes I through III. For patients with replacement, those with mitral structural failure had a third the risk of complication or death of those without structural failure. For patients operated on in the latter half of our series, the risks for patients in NYHA functional class IV were even greater; risks were also increased for patients with emergency surgery or previous cardiac surgery.

To assess the impact of missing data on the conclusions of this study, Kaplan-Meier survival curves were compared

TABLE 6. Hazard ratios for survival and for complication-free survival for patients who survived free of complications for at least 30 days

Event	Hazard ratio	95% CI
All patients		
Survival	0.88	0.47-1.65
Complication-free survival	0.74	0.42-1.32
Patients entered in 1988 or later		
Survival	0.73	0.27-2.02
Complication-free survival	0.62	0.25-1.62

Hazard ratio is for repair versus replacement.

in each of the two treatment groups for patients (1988 or later) with complete data included in the final models and patients with incomplete data who were not included in the final models. The respective hazard rates for mortality for patients with complete data relative to patients with incomplete data were 0.90 (95% CI 0.38-2.12) for repair and 1.75 (95% CI 0.50-6.12) for replacement.

Figure 4. Survival according to type of operation for patients with freedom from complications for 30 days. **A**, All patients; **B**, patients operated on in 1988 or later. *Filled diamonds* represent replacement; *open circles* represent repair.

Repair group: Outcome according to type of mitral reconstruction. In our series of patients who had repair operations performed in 1988 or later and survived for at least 30 days, the unadjusted risk of death after 30 days was 0.29 (95% CI 0.1-0.83) for repair with a ring annuloplasty

relative to simple suture repair, and the unadjusted risk of complication or death was 0.32 (95% CI 0.11-0.91) for ring annuloplasty repair relative to suture annuloplasty repair. Appendix Table 3 provides the Cox models and adjusted hazard ratios.

TABLE 7. Comparison of outcomes for repair versus replacement: The relative hazard ratios for death and for complications or death by patient characteristics

Baseline variables	Death		Complication or death	
	Hazard ratio	95% CI	Hazard ratio	95% CI
NYHA functional class				
I, II, or III	0.264	0.050-1.386	0.187	0.034-1.021
IV	0.957	0.444-2.063	0.753	0.370-1.532
Preoperative angina				
Yes	0.151	0.015-1.467	0.151	0.015-1.467
No	0.965	0.367-2.540	0.665	0.274-1.612
Congestive heart failure				
Yes	NA	NA	NA	NA
No	0.717	0.364-1.411	0.545	0.287-1.033
Type of mitral regurgitation				
Acute	0.495	0.238-1.026	0.453	0.224-0.913
Chronic	0.543	0.076-3.872	0.297	0.049-1.789
Emergency				
No	0.394	0.179-0.870	0.343	0.159-0.741
Yes	1.82	0.409-8.102	1.003	0.285-3.527
Diabetes				
Yes	0.538	0.208-1.393	0.538	0.208-1.393
No	0.773	0.288-2.073	0.51	0.213-1.218
Structural failure				
No	0.574	0.256-1.288	0.41	0.190-0.882
Yes	0.705	0.189-2.631	0.557	0.161-1.927
Isolated annular dilation				
Yes	0.779	0.261-2.322	0.499	0.180-1.379
No	0.32	0.129-0.794	0.336	0.136-0.830
Previous cardiac surgery				
No	0.638	0.281-1.447	0.441	0.208-0.932
Yes	1.46	0.382-5.579	1.004	0.3-3.36
Coronary artery bypass grafting				
No	0.166	0.03-0.915	0.166	0.03-0.915
Yes	0.94	0.246-2.078	0.647	0.314-1.334
Gender				
Male	0.91	0.289-2.864	0.736	0.259-2.093
Female	0.492	0.214-1.132	0.422	0.189-0.94
Age				
≤60 y	1.479	0.161-13.591	0.525	0.095-2.893
>60-70 y	0.957	0.262-3.501	0.75	0.238-2.364
>70 y	0.406	0.171-0.963	0.406	0.171-0.963

Hazard ratios are for the end point in the repair group versus the replacement group estimated from Cox proportional hazard models. For patients entered in 1988 or later.

Discussion

The central questions pertinent to the treatment of ischemic mitral insufficiency by reconstructive techniques include effectiveness, appropriateness, and long-term benefits. Although none of these questions can be answered directly from the data in this 2-decade nonrandomized experience, several conclusions can be drawn.

Is Mitral Reconstruction an Effective Treatment Option?

Although the different exploratory statistical approaches do not permit us to conclude that there is an independent impact (positive or negative) of operative procedure, the immediate

postoperative outcomes were most predicated on the covariates of NYHA functional class, emergency surgery, and previous cardiac surgery. In almost every patient baseline subgroup the comparison of reconstruction with replacement demonstrated a hazard ratio of less than unity for the risk of death or complication within 30 days. This result suggests evidence of improved immediate outcomes among patients selected for mitral valve reconstruction. In fact, the 1-year survival for patients who underwent reconstruction in 1988 or later was 78%, and the relative risk of death during the follow-up period for patients who were in NYHA functional classes I through III was a third that of patients in NYHA functional class IV.

Figure 5. Complication-free survival according to type of operation for patients with freedom from complications for 30 days. **A**, All patients; **B**, patients operated on in 1988 or later. *Filled diamonds* represent replacement; *open circles* represent repair.

For Which Patients Is Repair Appropriate?

Although the applicability of reconstruction is easily appreciated in the subset of patients with chronic ischemia and annular dilation, it is noteworthy that 17% of the repairs in our

series were done in cases of acute ischemic mitral insufficiency. These cases are challenging to the surgeon because evaluation of the damage to the subvalvular apparatus may be difficult. Not only does structural damage (ruptured chordae

TABLE 8A. Cox models for survival and for complication-free survival

Event	Covariates	Hazard ratio	95% CI
All patients			
Complication-free survival	NYHA functional class (IV vs ≤III)	2.78	1.59-4.85
	Structural failure (yes vs no)	0.54	0.3-0.97
Survival	NYHA functional class (IV vs ≤III)	2.85	1.58-5.13
	Previous cardiac surgery (yes vs no)	2.15	1.15-4.03
Patients entered in 1988 or later			
Complication-free survival	NYHA functional class (IV vs ≤III)	4.4	1.8-10.8
	Previous cardiac surgery (yes vs no)	2.7	1.3-5.9
	Mitral regurgitation (acute vs chronic)	0.28	0.08-0.95
	Preoperative angina (yes vs no)	0.36	0.14-0.98
Survival	NYHA functional class (IV vs ≤III)	3.99	1.69-9.45
	Previous cardiac surgery (yes vs no)	2.79	1.28-6.09
	Mitral regurgitation (acute vs chronic)	0.15	0.03-0.66
	Preoperative angina (yes vs no)	0.34	0.13-0.91

TABLE 8B. Cox models for survival and complication-free survival excluding NYHA functional class and preoperative angina from covariables

Event	Covariates	Hazard ratio	95% CI
All patients			
Complication-free survival	Type of valve procedure (repair vs replacement)	0.55	0.35-0.87
	Structural failure (yes vs no)	0.47	0.27-0.84
	Diabetes (yes vs no)	1.77	1.22-2.87
Survival	Type of valve procedure (repair vs replacement)	0.61	0.36-0.99
	Structural failure (yes vs no)	9.31	1.28-67.63
	Congestive heart failure (yes vs no)	0.44	0.24-0.82
	Mitral regurgitation (acute vs chronic)	0.67	0.34-1.32
Patients entered in 1988 or later			
Complication free survival	Valve procedure (repair vs replacement)	0.61	0.32-1.16
	Previous cardiac surgery (yes vs no)	2.27	1.14-4.54
	Diabetes (yes vs no)	2.23	1.23-4.04
Survival	Valve procedure (repair vs replacement)	0.45	0.22-0.93
	Emergency operation (yes vs no)	2.12	1.06-4.24
	Mitral regurgitation (acute vs. chronic)	0.19	(0.06, 0.64)

TABLE 9. Cox proportional hazards models for repair and replacement groups separately

Treatments	Event	Covariates	Hazard ratio	95% CI
All patients				
Repair (n = 151)	Any complication or death	NYHA functional class (IV vs ≤III)	3.205	1.57-6.54
	Any death	NYHA functional class (IV vs ≤III)	2.81	1.37-5.75
Replacement (n = 70)	Any complication or death	Structural failure (yes vs no)	0.325	0.14-0.75
		Congestive heart failure (yes vs no)	2.88	0.39-21.26*
	Any death	Structural failure (yes vs no)	0.41	0.168-1.007*
Patients entered in 1988 or later				
Repair (n = 125)	Any complication or death	NYHA functional class (IV vs ≤III)	3.49	1.31-9.32
		Mitral regurgitation (acute vs chronic)	0.2	0.05-0.87
		Emergency operation (yes vs no)	2.25	1.06-4.76
	Any death	NYHA functional class (IV vs ≤III)	4.16	1.57-11.03
		Previous cardiac surgery (yes vs no)	3.82	1.64-8.89
Replacement (n = 33)	Any complication or death	Structure failure (yes vs no)	0.206	0.05-0.89
		Gender (male vs female)	2.49	0.69-9.02*
	Any death	Structure failure (yes vs no)	0.343	0.09-1.33*
		Gender (male vs female)	2.63	0.68-10.26*

*Included in best model from model selection process. Results from refitted model are shown.

or papillary muscle) need to be readily discerned, but subtle, ongoing pathologic processes of the subvalvular apparatus must also be accurately appraised. The few patients with valve reconstruction who required reoperation did so within a short period after the original operation. These reoperations were mainly because of further disruption of the subvalvular apparatus when the extent of damage to the subvalvular apparatus had not been fully appreciated initially. Although there was a trend toward further reintervention in the patients with valve repair, this difference can be attributed mainly to the learning curve associated with recognizing the extent of reconstruction in acute infarction. It is important to note that in our series there were no late valve-related deaths among patients undergoing further mitral valve surgery.

What Are the Long-term Benefits?

The 5-year survival among the patients with mitral reconstruction in this series compares favorably with those reported by others,^{5,6,13} which have ranged from approximately 64% to 75%. Strikingly, the various subsets of patients undergoing valve reconstruction had similar survivals regardless of the pathophysiologic mechanism of the regurgitation. The overall results are in sharp contrast to the study by Cohn and coinvestigators,⁶ which reported a 5-fold greater mortality among patients with ischemic mitral regurgitation undergoing valve reconstruction (56% freedom from death for repairs at 5 years compared with 91% for replacement). Cohn and coinvestigators⁶ suggested that it was not the mitral reconstruction itself that jeopardized patient survival; rather, annular dilation was a surrogate variable for the poor ventricular function that decreased late survival (5-year survival for reconstruction of annular dilation 43%). Cosgrove similarly reported a 3-year survival of only 48% among the patients who underwent mitral reconstruction for ischemic annular dilation. In contrast, in this study patients undergoing valve reconstruction for annular dilation had a 5-year survival of 71% (95% CI 61%-82%; Appendix Table 4).

Our experience with valve reconstruction for ischemic insufficiency included both simple suture annuloplasty and ring annuloplasty. Czer and coworkers² reported less postoperative mitral insufficiency after ring annuloplasty than after suture annuloplasty for patients with pure annular dilation. In this study both improved survival and improved complication-free survival were associated with remodeling ring annuloplasty.

This report provides additional evidence that the well-described benefits of valve reconstruction, such as superior freedom from the valve-related complications of embolism and endocarditis and from anticoagulant-related complications, also apply to patients with ischemic disease.

Limitations of the Study

The term *ischemic mitral insufficiency* includes multiple pathologic disease processes with the final result of mitral

insufficiency. Our analysis, which began before the availability of routine echocardiography, used a classification system similar to that proposed by Rankin and colleagues⁷ in the 1980s. Recently, with the advent of transesophageal echocardiography and detailed leaflet analysis, a more functional analysis has been developed with subgrouping of either structural insufficiency or functional insufficiency. Structural insufficiency includes those patients with ruptured or elongated chordae or papillary muscle defects (type 2). Functional insufficiency includes those patients with restricted leaflet motion (type 3b) and those with annular dilation (type 1). The classification system that we used can be roughly translated into structural and functional categories. As more detailed studies of patients with ischemic mitral insufficiency are performed, the functional analysis will become the standard.

This patient series encompassed a 2-decade surgical experience. This was a retrospective study without randomization, and the relatively small numbers in each group of patients with this fairly rare disease made case matching impractical. When the assignment of patients to treatments is not random but is the result of some selection process that may be biased, the attribution of causality becomes difficult. In our series the choice of type of surgery was related to characteristics of the patient at presentation as well as to other unknown selection biases on the part of the surgeons. In addition, in our series the 20-year span encompassed changing technology and surgical techniques. Although cold blood cardioplegia was used throughout the series, the most significant change in our surgical practice occurred in the middle portion of this experience with the introduction of retrograde cardioplegia. The improved distribution of cardioplegia with this method allowed us to more aggressively pursue mitral reconstruction after this point in time, thus changing surgical practice. In addition, the repair operation was infrequent before 1988. Our focus on patients with surgery in 1988 or later allowed us to minimize the effects of these changes on our results.

Conclusions

These analyses suggest that the type of surgery has little influence on prognosis after adjustment for NYHA functional class and presence of angina at time of surgery. After exclusion of these two confounding variables, the risk of death and the risk of complication or death within 30 days of surgery were markedly reduced for patients who underwent repair relative to patients who underwent replacement. Similar results were obtained for total mortality and risk of complication or death. When we examined the repair group separately, the risk for death or complication was 3 times greater for patients in NYHA functional class IV at surgery than for those who were NYHA functional classes I through III. From the models developed for each cohort separately,

we have discerned the factors associated with increased risks for patients selected for repair and for patients selected for replacement that can provide guidance to the surgeon with respect to selection of patients for these procedures.

We make the following recommendations. Aside from catastrophic, acute structural mitral valve failure, mitral valve reconstructive techniques are applicable in cases of both acute and chronic ischemic mitral insufficiency. Those patients with leaflet prolapse related to limited rupture of chordae or papillary muscle tips should undergo repair with the appropriate technique. Caution should be applied in the case of patients with acute insufficiency related to ischemic or infarcted papillary muscles; rather than relying on jeopardized tissue for reconstruction, mitral replacement should be performed in these cases. Likewise, patients with severe ventricular-papillary dysfunction often have more reliable correction with valve replacement. Finally, patients with chronic annular dilation have excellent results with mitral valve reconstruction and ring annuloplasty. For these patients valve repair provides superior freedom from valve-related complications with equivalent survival and therefore is preferred. In summary, in the case of ischemic mitral valve disease, it is up to the operating surgeon to appropriately choose valve repair or replacement, depending on the acuity of the presentation and the pathophysiologic mechanism involved.

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Appendix TABLE 1. Survivals and complication-free survivals for all patients

Years	Replacement			Repair		
	No. at risk	Survival	95% CI	No. at risk	Survival	95% CI
Survival						
1	70	0.7	0.59-0.81	151	0.76	0.69-0.84
2	43	0.68	0.56-0.79	82	0.72	0.64-0.80
3	33	0.63	0.51-0.75	55	0.71	0.62-0.79
4	24	0.6	0.47-0.73	43	0.71	0.62-0.79
5	21	0.57	0.44-0.70	29	0.68	0.58-0.77
Complication-free survival						
1	70	0.62	0.50-0.74	151	0.76	0.68-0.83
2	39	0.55	0.43-0.67	81	0.7	0.62-0.78
3	26	0.5	0.37-0.63	54	0.67	0.58-0.76
4	18	0.47	0.33-0.60	41	0.67	0.58-0.76
5	15	0.47	0.33-0.60	28	0.64	0.54-0.74

Appendix TABLE 2. Survivals and complication-free survivals for patients entered in 1988 or later

Years	Replacement			Repair		
	No. at risk	Survival	95% CI	No. at risk	Survival	95% CI
Survival						
1	33	0.7	0.53-0.86	127	0.77	0.69-0.84
2	19	0.65	0.47-0.83	66	0.74	0.66-0.82
3	11	0.65	0.50-0.83	41	0.72	0.63-0.81
4	6	0.51	0.22-0.79	30	0.72	0.62-0.81
5	4	0.34	0.01-0.66	17	0.71	0.62-0.81
Complication-free survival						
1	33	0.63	0.46-0.81	127	0.76	0.68-0.84
2	17	0.58	0.40-0.76	65	0.73	0.65-0.81
3	9	0.49	0.25-0.71	41	0.71	0.62-0.80
4	4	0.29	0.00-0.61	30	0.71	0.62-0.80
5	2	0.29	0.00-0.61	17	0.71	0.62-0.80

Appendix TABLE 3. Cox models for late cardiac survival and for complication-free survival (for repair group only)

Event	Covariates	Hazard ratio	95% CI
Complication-free survival	NYHA functional class (IV vs ≤III)	3.72	1.08-12.78
	Previous cardiac surgery (yes vs no)	3.57	1.01-12.61
	Ring annuloplasty vs suture annuloplasty	0.287	0.1-0.83
Death	NYHA functional class (IV vs ≤III)	3.56	1.01-12.5
	Previous cardiac surgery (yes vs no)	3.88	1.06-14.15
	Ring annuloplasty vs suture annuloplasty	0.26	0.09-0.78

Appendix TABLE 4. Survivals and complication-free survivals of patients in repair group entered in 1988 or after with isolated annular dilation

Years	No. at risk	Survival	95% CI
Survival			
1	90	0.75	0.65-0.85
2	47	0.71	0.61-0.82
3	28	0.71	0.61-0.82
4	20	0.71	0.61-0.82
5	13	0.71	0.61-0.82
Complication-free survival			
1	90	0.74	0.64-0.83
2	46	0.7	0.59-0.80
3	28	0.7	0.59-0.80
4	20	0.7	0.59-0.80
5	13	0.7	0.59-0.80