The impact of intraoperative residual mild regurgitation after repair of degenerative mitral regurgitation

Bartlomiej Imielski, MD,[a] S. Chris Malaisrie, MD,[a] Duc Thinh Pham, MD,[a] Jane Kruse, RN, BSN,[a] Adin-Cristian Andrei, PhD,[b] Menghan Liu, MS,[a] James L. Cox, MD,[a] and Patrick M. McCarthy, MD[a]

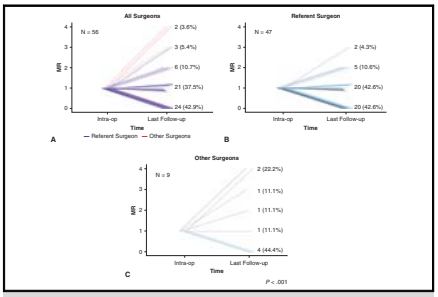
ABSTRACT

Objectives: During degenerative mitral repair, surgeons must decide if further repair is warranted for residual mild mitral regurgitation. We examined the incidence of mild mitral regurgitation, late echocardiographic and clinical outcomes, and influence of surgical experience in decision making.

Methods: From April 2004 to June 2018, 1155 of 1195 patients with pure degenerative disease underwent repair (97% repair rate). Propensity score matching was performed between patients with trace/no mitral regurgitation and patients with mild residual mitral regurgitation. Late echocardiographic outcome and freedom from reoperation were compared using competing-risks models. A comparison of outcomes of the referent surgeon (89.8% of repairs) with all other surgeons was performed.

Results: Mild mitral regurgitation was present in 73 patients (6%). Propensity score–matched analyses compared 69 patients with mild mitral regurgitation with 198 patients without mitral regurgitation. Late moderate or greater mitral regurgitation was higher in those with mild mitral regurgitation than in those with no mitral regurgitation (17% vs 7%, $P = .033$), as was late moderate-severe or greater mitral regurgitation (6% vs 1%, $P = .016$). Ten-year freedom from reoperation was low in both groups (99.5% no vs 96.9% mild; $P = .10$). The referent surgeon had fewer patients with mild residual mitral regurgitation (6% vs 11%, $P = .027$) and less progression of mitral regurgitation compared with other surgeons (late moderate or greater mitral regurgitation 6% vs 15%, $P = .002$).

Conclusions: Residual mild mitral regurgitation was uncommon, and late progression to moderate or greater mitral regurgitation was rare and never led to late mitral reoperation. Experienced surgeons may be better able to determine repairs likely to remain stable, and most mild residual mitral regurgitation does not require re-repair. (J Thorac Cardiovasc Surg 2021;161:1215-24)



Late MR grade in follow-up in patients with mild residual MR after MV repair.

Central Message

Residual mild MR is uncommon (6%) after DMR repair. Progression to moderate or more MR is higher compared with those without MR but was not associated with more reoperations.

Perspective

The results of this study demonstrate the importance of a successful DMR repair. Mild residual MR is uncommon, 6% in this series, and in most patients it resolved or stayed the same over time. Surgeon expertise appears to be important to minimize late MR progression. In those with mild residual MR, 10-year results indicate a second crossclamp and further repair is not necessary for most patients.

See Commentary on page 1225.

Expectations for a perfect mitral repair are high. According to the American Heart Association/American College of Cardiology guidelines for the management of valvular heart

From the [a]Division of Cardiac Surgery, Department of Surgery, Bluhm Cardiovascular Institute, Northwestern University Feinberg School of Medicine and Northwestern Medicine, Chicago, Ill; and [b]Division of Biostatistics, Department of Preventive Medicine, Northwestern University, Chicago, Ill.

Institutional Review Board Approval: Northwestern University STU00012288.

Read at the 99th Annual Meeting of The American Association for Thoracic Surgery, Toronto, Ontario, Canada, May 4-7, 2019.

Received for publication May 3, 2019; revisions received Sept 3, 2019; accepted for publication Oct 2, 2019; available ahead of print Oct 17, 2019.

Address for reprints: Patrick M. McCarthy, MD, Division of Cardiac Surgery, University Feinberg School of Medicine, Northwestern University, 201 East Huron St, Suite 11-140, Chicago, IL 60611-2908 (E-mail: Patrick.McCarthy@nm.org).

0022-5223/$36.00

https://doi.org/10.1016/j.jtcvs.2019.10.033

Scanning this QR code will take you to the table of contents to access supplementary information. To view the AATS Meeting Webcast, see the URL next to the webcast thumbnail.

Abbreviations and Acronyms

DMR = degenerative mitral regurgitation
MR = mitral regurgitation
MV = mitral valve
PS = propensity score
TEE = transesophageal echocardiography

disease, mitral valve (MV) repair is recommended in preference to replacement, even for asymptomatic patients, when "successful and durable repair without residual mitral regurgitation (MR) is greater than 95% with an expected mortality rate of less than 1% when performed at a Heart Valve Center of Excellence."[1,2] Uncorrected residual (MR still present on intraoperative postpump transesophageal echocardiogram [TEE]) moderate MR has been demonstrated to lead to a significant risk for late progression of MR and need for reoperation,[3,4] but the data on residual mild MR are limited.[5-7] Therefore, when faced with residual mild MR after degenerative MR (DMR) repair, the surgeon has little data to guide an important decision, that is, whether to go back on bypass, reclamp and arrest the heart, and try to re-repair the valve, or is it safe and reasonable to accept a small amount of residual mild MR?

We sought to determine the intraoperative incidence of mild residual MR determined by postpump TEE, the clinical characteristics of these patients compared with those with trivial or no MR, the echocardiographic characteristics of the mechanism of mild MR, the late MR progression and reoperation in both groups, and the MR progression in patients treated by a specialist MV surgeon (referent surgeon) compared with all other surgeons.

MATERIALS AND METHODS

Patients and Study Design

This study is a single-institution, multi-surgeon review of consecutive patients undergoing surgical MV repair for type II degenerative disease. Preoperative, intraoperative, and postoperative data were obtained from the Cardiovascular Research Database in the Clinical Trial Unit of the Bluhm Cardiovascular Institute at Northwestern Memorial Hospital (Institutional Review Board at Northwestern University STU00012288) and medical record review. Patients who refused participation in the registry were excluded.

Patients who underwent first-time nonemergency DMR surgery with or without other cardiac surgery between April 1, 2004, and June 30, 2018, were included. Other MR etiologies, or "mixed" lesions with DMR and other etiologies together, were excluded. The primary technique of repair was based on resection with (1) leaflet reconstruction to return the normal 2:1 ratio of anterior to posterior leaflet length using direct measurement; (2) complete remodeling ring repair; and (3) ring size based on the anterior leaflet height and informed by the distance from the coaptation point to the nearest point of the septum. No artificial chords were used by the referent surgeon. The technique of repair and results will be the subject of a separate article. Patients in this report underwent routine intraoperative TEE read as mild before leaving the operating room by cardiologists or anesthesiologists with level 3 echocardiography certification according to the American Society of Echocardiography guidelines. Patients underwent predischarge echocardiograms and received surveys at 3, 6, and 12 months after surgery and annually thereafter to report medical visits, and tests. Medical records were obtained to verify operations, echocardiogram reports, or hospitalizations. On predischarge and late echocardiograms, intermediate reports were upgraded so that trivial to mild MR was in the mild (1+) MR group, and mild to moderate MR was in the moderate (2+) MR group. Moderate to severe MR was graded 3+, and severe MR was graded 4+. The Society of Thoracic Surgery definitions were used to determine complications. Mortality data were aggregated continuously consulting sources that included (1) CARD registry; (2) reviews of medical records and correspondence with the treating physician; (3) online death searches and genealogy resources (ancestry.com); and (4) newspaper death notices.

Statistical Analysis

Variables with continuous distributions were summarized using means and standard deviations, and group comparisons between patients with no MR versus mild MR were based on the 2-sample *t* test with Satterthwaite's approximation or on the Wilcoxon rank-sum test. Counts and percentages were used to summarize variables that had discrete distributions, whereas group comparisons relied on the chi-square or Fisher exact test. Propensity score (PS) matching was used to reduce confounding due to baseline differences. Patients with no MR were PS matched 3-to-1 to mild MR cases. Variables used to construct the PS model were age, body surface area, body mass index, $CHADS_2$ (Congestive heart failure, Hypertension, Age 75 years or older, Diabetes mellitus, Stroke or transient ischemic attack) score, gender, diabetes, hypercholesterolemia, hypertension, chronic obstructive pulmonary disease, peripheral vascular disease, prior congestive heart failure, prior pacemaker, repeat sternotomy, prior coronary artery bypass graft, prior valve surgery, and MV repair technique (Alfieri stitch, commissuroplasty, and chordal transfer). Matching involved a greedy algorithm with a caliper of size 0.1 logit PS standard deviation units. Standardized mean differences were used to assess covariate balance after PS matching, and absolute values less than 0.2 were considered to reflect adequate balance. MR progression, freedom from reoperation, and overall survival were summarized using cumulative incidence functions for competing risks models, and group comparisons involved Gray's test. Statistical significance was declared at 2-sided 5% alpha level, and no adjustments for multiplicity were made. Given the possibility of serial MR assessments per patient, late moderate or greater MR (as a binary yes/no outcome) was also analyzed using generalized linear modeling, and odds ratio were obtained using generalized estimating equations under a working independence within-individual correlation structure. For robustness purposes, we performed a supplemental PS-based freedom from late MR analysis using inverse PS weighting. Specifically, weights for patients with mild MR were 1/PS, whereas for the patients with no MR they were equal to PS/(1-PS). Weights were trimmed at 20 to reduce the potential for excessively large influence from few observations. All analyses were performed using SAS, version 9.4 software (SAS Institute, Inc, Cary, NC) and R v. 3.2.1 (www.R-project.org).

RESULTS

A total of 1195 patients with DMR met inclusion criteria, and of those, 1155 (96.7%) underwent repair. All operations were performed by the referent surgeon (P.M.M.) and 10 other nonreferent surgeons. Repair was performed by the referent surgeon in 1037 of 1060 patients (97.8%) and in 118 of 135 patients (87.4%) by the other surgeons. The mean duration of clinical follow-up was 4.7 $\pm$ 3.5 years, median clinical follow-up was 4 years (1.7, 7), and echocardiography follow-up was 3.3 $\pm$ 3 years, median of 3.1 (1.1, 6.1) years

TABLE 1. Preoperative characteristics by intraoperative mitral regurgitation status in original and propensity score–matched groups

Variable	Entire cohort						3-to-1 PS matched				
	N	No MR (N = 1082)		Mild MR (N = 73)		*P* value	No MR (N = 198)		Mild MR (N = 69)		Standardized mean difference
Age, y	1155	60.4	± 12.3	64.2	± 12.5	.012	64.5	± 12.1	64.7	± 12.4	0.02
Gender (female)	1155	346	(32)	24	(33)	.87	72	(36)	24	(35)	−0.03
Left ventricular ejection fraction	1145	60.0	(55.0-65.0)	62.0	(59.5-65.0)	.24	62.0	(58.0-65.0)	63.0	(59.0-65.0)	0.03
Dyslipidemia	1155	478	(44)	41	(56)	.046	123	(62)	40	(58)	−0.08
Hypertension	1155	542	(50)	37	(51)	.92	113	(57)	34	(49)	−0.16
Cerebrovascular disease	1154	46	(4)	5	(7)	.30	13	(7)	4	(6)	−0.03
Atrial fibrillation history	1155	273	(25)	20	(27)	.68	60	(30)	18	(26)	−0.09
Coronary artery disease	1108	211	(20)	22	(31)	.027	58	(29)	22	(32)	0.06
Congestive heart failure	1154	202	(19)	19	(26)	.12	44	(22)	17	(25)	0.06
NYHA class III/IV	1108	175	(17)	17	(25)	.08	46	(24)	15	(23)	−0.01
Prior coronary artery bypass surgery	1155	13	(1)	9	(4)	.04	7	(4)	3	(4)	0.02
Repeat sternotomy	1155	23	(2)	3	(4)	.27	7	(4)	3	(4)	0.04

Values are mean ± standard deviation; n (%); or median (first quartile, third quartile). *MR*, Mitral regurgitation; *NYHA*, New York Heart Association.

(85% complete). Active follow-up is available for 92% of patients, and the remaining 8% have been followed for an average of 4 ± 3 years.

Unmatched Groups

Of 1155 patients who underwent MV repair, 1082 (94%) had none/trivial residual MR on intraoperative TEE, 73 (6%) had mild residual MR, and 0 had moderate or greater residual MR. The referent surgeon performed 1037 (90%) of the repairs, and those results were compared with those for all other surgeons (n = 118).

There were several differences at baseline between the no MR group and mild MR groups (Table 1). Patients in the mild MR group were older (64 ± 13 years vs 60 ± 12 years, $P = .012$), had a higher Society of Thoracic Surgeons risk score (0.6 [0.4-1.9] vs 0.4 [0.3-0.9, $P = .01$), had more coronary artery disease (31% vs 20%, $P = .027$), and had more prior coronary artery bypass (4% vs 1%, $P = .04$). Urgent procedure status was also higher in the mild MR group (14% vs 6%, $P = .005$). Intraoperative findings associated with mild MR included more A3 prolapse (27% vs 15%, $P = .038$), P3 prolapse (14% vs 7%, $P = .06$), and A2 flail (11% vs 5%, $P = .06$). Procedure-related characteristics (Table 2) associated with mild residual MR were longer crossclamp time (83 [67.0-103.0] vs 75 [63.0, 92.0] minutes, $P = .05$) and perfusion time (99 [83.0-128.0] vs 89 [74.0-113.0] minutes, $P = .009$). Both groups included a small number of patients who initially had moderate MR and had a second crossclamp for repair (22/1155 or 2% of all repairs). After repair, these patients were included in the mild (N = 2) or no MR (N = 20) group. The size of the annuloplasty ring, the type of repair technique, primary versus redo sternotomy, and the additional ablation for atrial fibrillation did not differ between groups. Postoperative characteristics between groups are shown in Table 3.

There were 2 reoperations in the mild MR group during the index hospitalization, but none after discharge. One patient had an uneventful valve repair in 2005, but in the intensive care unit the patient developed hemodynamic instability, later associated with a transfusion reaction, and underwent emergency mitral replacement for systolic anterior motion. In 2013, a patient underwent complex repair for Barlow's valve with resection, sliding plasty, chord transfer, and AF ablation and had trivial to mild MR after weaning from bypass. Routine predischarge echocardiogram showed moderate to severe MR from a tear at the base of the leaflet where the sliding plasty was performed. At reoperation on postoperative day 6, the tear was repaired using an autologous pericardial patch, and echocardiogram at 6 years showed mild-moderate MR.

Patients in the mild MR group were more likely to progress to moderate or more MR after discharge than patients in the no MR group ($P < .001$) (Figure 1, *A*). Progression of MR over time is shown in Figure 2. The progression from mild residual MR to late moderate or more recurrent MR depended on the surgeon (Figure 3). For the referent surgeon, the progression was less (6% vs 15%, $P = .002$) than for the other surgeons, indicating that with experience patients likely to remain stable can be selected by intraoperative echocardiographic criteria. Generalized estimating equation–based unadjusted odds ratio for moderate or greater MR was 6.6 (95% confidence interval, 2.7-16.3, $P < .001$) when comparing patients with mild MR with patients with no MR

TABLE 2. Operative characteristics

Variable	Entire cohort N	No MR (N = 1082)		Mild MR (N = 73)		*P* value	3-to-1 PS matched No MR (N = 198)		Mild MR (N = 69)		*P* value
Perfusion time (min)	1155	89.0	(74.0-113.0)	99.0	(83.0-128.0)	.009	91.0	(76.0-112.0)	99.0	(83.0-119.0)	.05
Crossclamp time (min)	1155	75.0	(63.0-92.0)	83.0	(67.0-103.0)	.05	75.5	(63.0-92.0)	83.0	(67.0-103.0)	.048
Coronary artery bypass graft	1155	164	(15)	11	(15)	.98	30	(15)	11	(16)	.88
Aortic valve surgery	1155	51	(5)	4	(5)	.77	10	(5)	4	(6)	.81
Tricuspid valve surgery	1155	111	(10)	11	(15)	.20	25	(13)	9	(13)	.93
Atrial fibrillation ablation surgery	1155	272	(25)	23	(32)	.23	60	(30%)	21	(30%)	.98
Alfieri repair	1155	79	(7%)	6	(8%)	.77	18	(7%)	12	(6%)	6
Commissuroplasty	1155	112	(10%)	11	(15%)	.21	45	(17%)	34	(17%)	11
Chordal transfer	1155	158	(15%)	12	(16%)	.67	48	(18%)	36	(18%)	12
Additional crossclamp related to mitral	22	22	(2)	0	(0)	.015	3	(1.5)	0	(0)	.046
Surgery type	1155					.005					.67
Elective		1022	(94)	63	(86)		176	(89)	60	(87)	176
Urgent		60	(6)	10	(14)		22	(11)	9	(13)	22
Implant size	1152	34.0	(32.0-36.0)	34.0	(32.0-36.0)	.98	34.0	(30.0-36.0)	34.0	(32.0-36.0)	.18
P1 prolapse	820	38	(5)	0	(0)	.09	0	(0)	0	(0)	.08
P2 prolapse	872	259	(32%)	12	(21%)	.11	37	(25%)	12	(23%)	.80
P3 prolapse	821	54	(7)	8	(14)	.06	7	(5)	8	(15)	.021
A2 flail	629	28	(5)	5	(11)	.06	3	(3)	5	(12)	.016
A3 prolapse	647	91	(15)	13	(27)	.038	16	(13)	11	(24)	.10

Values are mean ± standard deviation; n (%); or median (first quartile, third quartile). *MR*, mitral regurgitation.

(reference). Upon adjustment for covariates used in the PS model, the odds ratio was equal to 6.9 (2.0-24.0; $P = .002$). The inverse PS weighting analysis depicted in Figure E1 confirms the higher likelihood of developing late moderate or greater MR among patients with mild MR. On average, the progression was identified within 3.5 ± 2.8 years, with a median of 2.7 and range of 0.1 to 11.0 years.

At 5 years, freedom from MV reoperation was 99.5% in patients with no MR and 97.0% in patients with mild MR ($P = .003$), whereas corresponding 10-year values were 99.5% and 97.0%, respectively ($P = .003$). The unadjusted difference in all-cause late mortality was significant ($P < .001$, Figure E2), but after matching, this was not different.

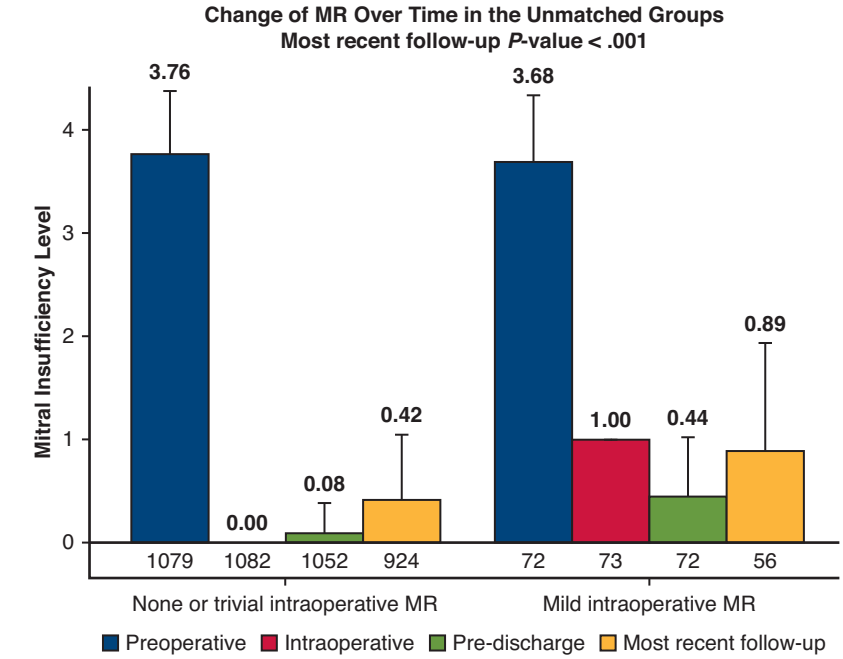
Propensity Score–Matched Groups

On the basis of standardized mean differences, the no MR group (N = 198) showed no differences in preoperative

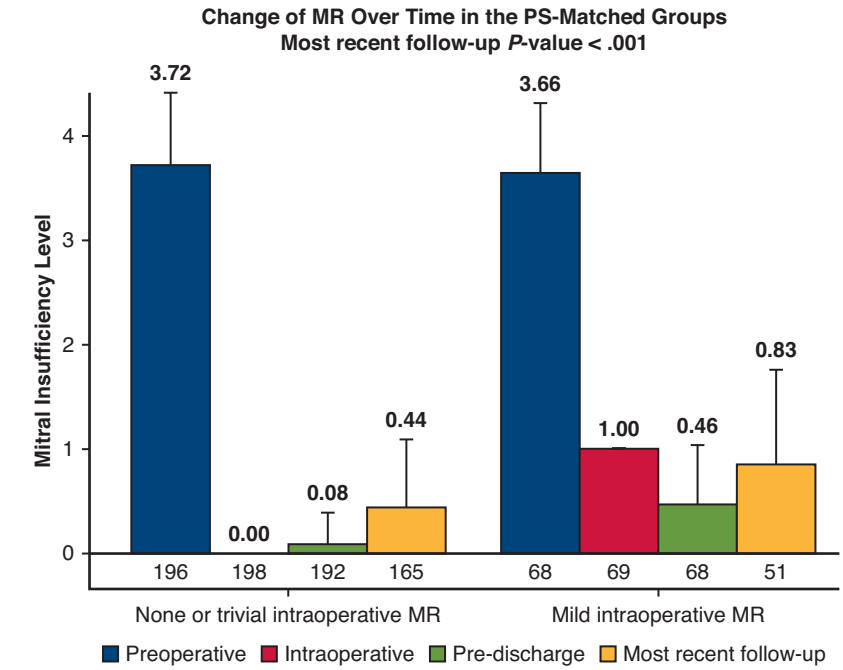
TABLE 3. Postoperative characteristics

Variable	Entire cohort N	No MR (N = 1082)		Mild MR (N = 73)		*P* value	3-to-1 PS matched No MR (N = 198)		Mild MR (N = 69)		*P* value
Postoperative length of stay (d)	1019	5.0	(4.0-7.0)	5.0	(4.0-7.0)	.32	5.0	(5.0-7.0)	5.0	(4.0-7.0)	.29
Predischarge ejection fraction	1111	55.0	(50.0-60.0)	55.0	(52.0-60.0)	.30	55.0	(50.0-60.0)	55.0	(52.0-60.0)	.24
Follow-up ejection fraction	978	58.0	(53.0-61.0)	59.5	(53.0-62.5)	.74	58.0	(53.0-62.0)	59.5	(53.0-62.5)	.99
Dialysis required	1155	5	(0)	1	(1)	.30	1	(1)	0	(0)	.55
Multisystem failure	1155	1	(0)	0	(0)	.79	0	(0)	0	(0)	
Discharged to home	1151	982	(91)	61	(84)	.033	172	(87)	57	(83)	.33
30-d mortality	1155	6	(0.6%)	0	(0)	.52	3	(1.5%)	0	(0)	.30
MV reoperation	1070	4	(0.4%)	2	(2.7%)	.006	1	(0.5%)	2	(2.9%)	.09

Values are mean ± standard deviation; n (%); or median (first quartile, third quartile). *MR*, Mitral regurgitation; *MV*, mitral valve.



A



B

FIGURE 1. Mean and standard deviation values for degree of MR observed at 4 time points (preoperative, intraoperative, predischarge, and most recent follow-up) in the 2 groups of interest: patients with none or trivial intraoperative MR, and those with mild or greater intraoperative MR. Separate summaries are provided in the unmatched groups (A) and PS-matched groups (B). *MR*, Mitral regurgitation; *PS*, propensity score.

characteristics compared with the mild MR group (N = 69) (Table 1 and Figure E3). There were no significant differences in the size of annuloplasty ring, the type of repair technique, and primary versus repeat sternotomy, and the need for re-crossclamp was no longer different. However, differences were observed with longer crossclamp time (83 [67.0-103.0] vs 75 [63.0-92.0] minutes; $P = .05$), perfusion time (99 [83.0-119.0] vs 91 [76.0-112.0] minutes; $P = .05$), and more P3 prolapse (15% vs 5%, $P = .02$) and A2 flail (12% vs 3%, $P = .02$) in the mild MR group.

Overall, patients in the mild MR group were still more likely to develop moderate or more MR during follow-up compared with the no MR group ($P < .001$) (Figure 1, *B*). Freedom from MV reoperation at 5 years was 99.5% with

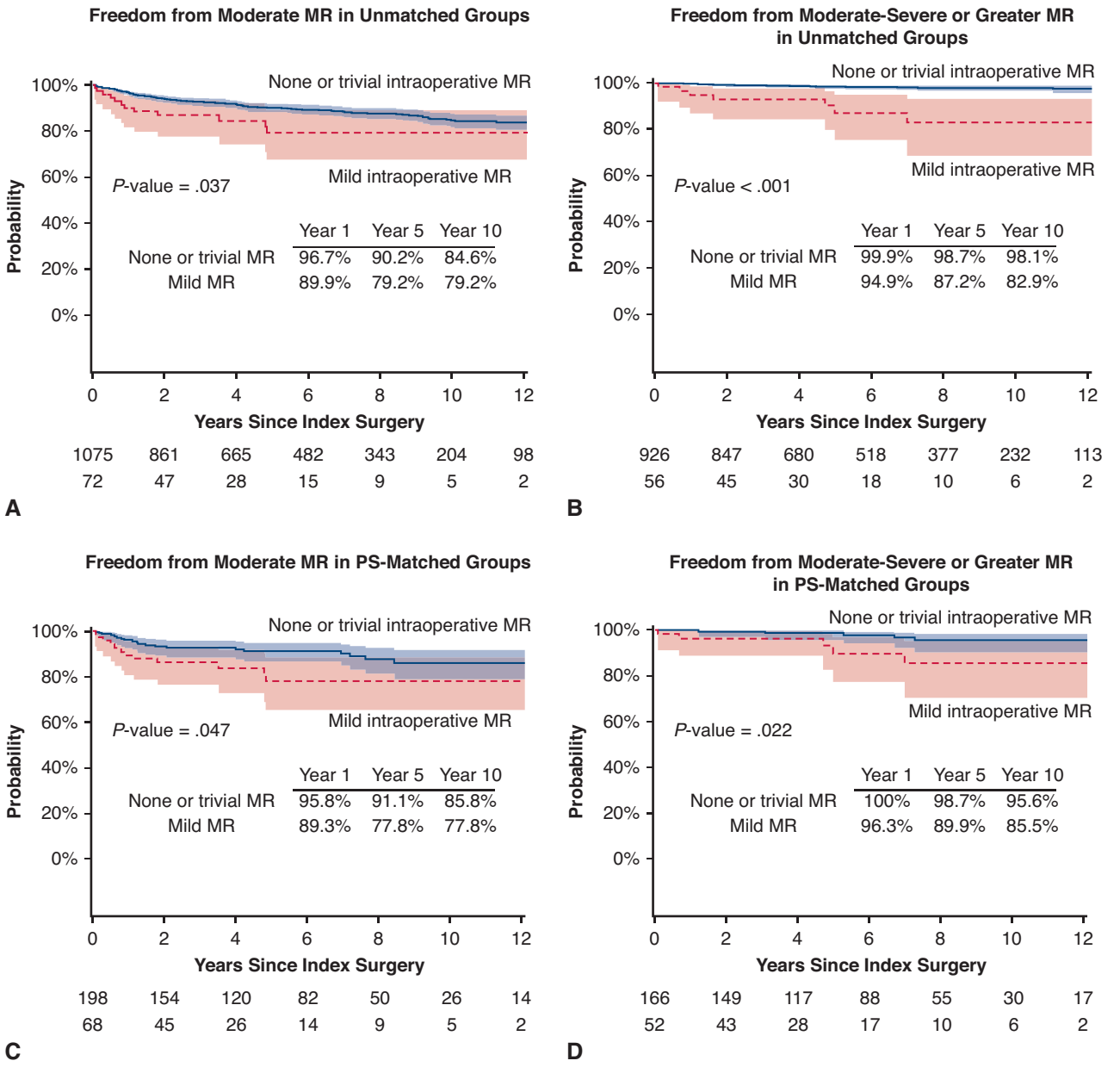


FIGURE 2. Freedom from moderate MR at any time during follow-up in the unmatched groups (A) and the PS-matched groups (C). B and D, Freedom from moderate-severe or greater MR in the unmatched groups and the PS-matched groups, respectively. *MR*, Mitral regurgitation; *PS*, propensity score.

no MR and 96.9% in patients with mild MR ($P = .10$), whereas at 10 years the corresponding values were 99.5% and 96.9%, respectively ($P = .10$). There was no significant difference in all-cause late mortality ($P = .33$, Figure E1).

Echocardiographic Examination of Mechanism of Residual Mild Mitral Regurgitation

We sought to determine if there were anatomic criteria or patterns that might separate patients in whom the MR stayed stable or decreased to no MR in follow-up (N = 57), compared with patients (N = 9) who progressed to recurrent MR of moderate or greater severity. Intraoperative TEE images were reviewed for leaflet perforation that may progressively tear and residual prolapse or leaflet restriction that may progress. We also tried to identify jets along an irregular coaptation line that may remain stable. In this retrospective review of images, the quality to determine exact mechanisms of residual MR was limited. Blinded review of intraoperative echocardiographic images did not reveal any specific technical issues to predict which patients would progress to in follow-up. Bileaflet and anterior leaflet prolapse were was not contributing factors. Some patients with postpump reduced left ventricular function had MR resolution over time as the ejection fraction improved, perhaps indicating better coaptation with improved contractility.

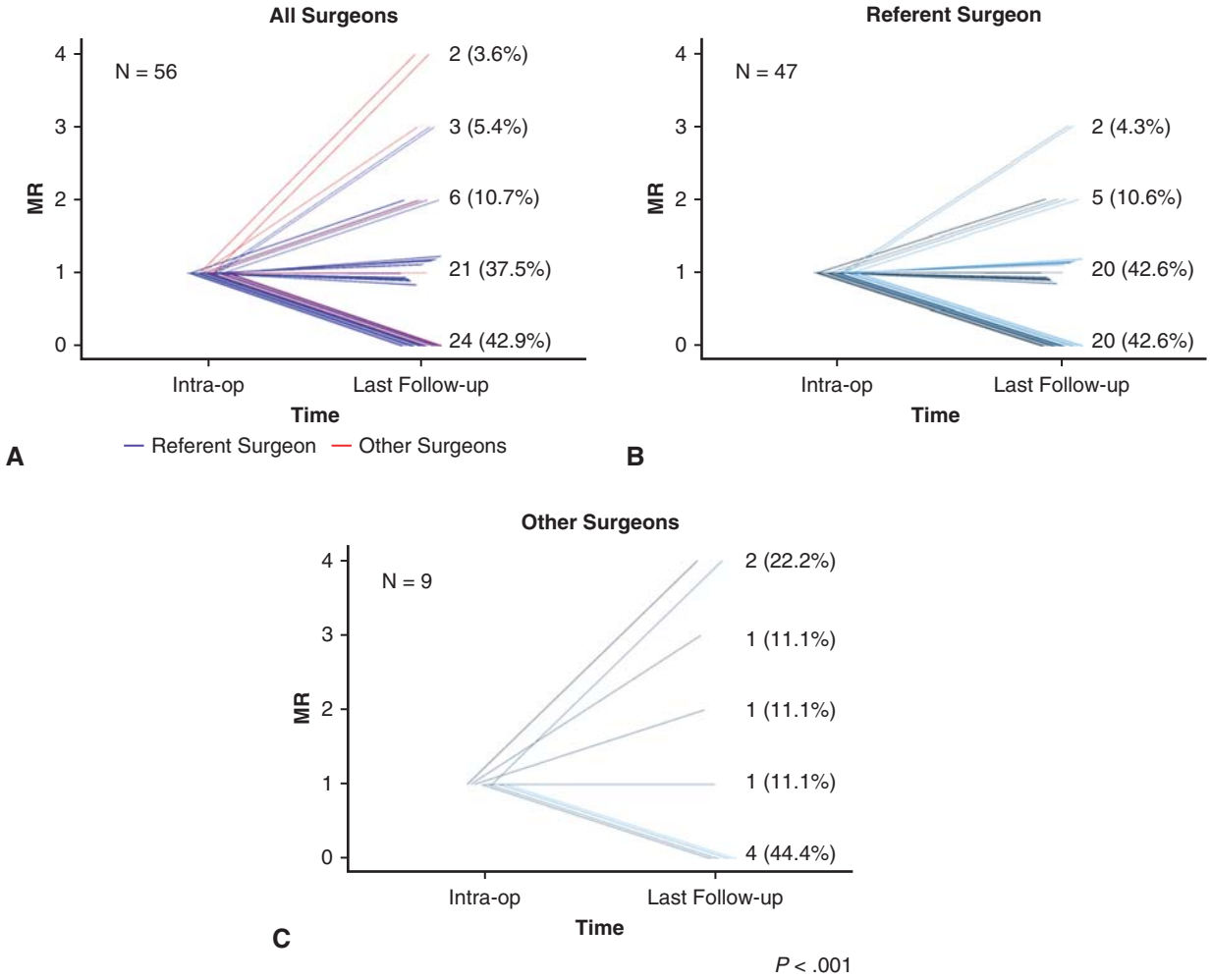


FIGURE 3. The evolution of intraoperative mild MR over time to most recent follow-up echocardiography in unmatched patients showed that most often late MR was downgraded as 0 or continued as mild, but in 20% it progressed (A). But when comparing the evolution of MR between the referent surgeon and "all other" surgeons, there was significantly less progression ($P = .022$) for the referent surgeon (B) compared with all other surgeons (C). *MR*, Mitral regurgitation.

DISCUSSION

We believe our study to be the largest series investigating the clinical outcomes of mild residual MR after DMR repair. We found that mild MR is uncommon with 94% of patients leaving the operating room with no MR. Goldstone and colleagues[8] found a similar 5.5% rate of residual MR in the Stanford series, but they did not report on late outcomes in this specific subgroup. Mild MR decreased at follow-up to trivial or no MR in most patients (42.9%), and MR stayed mild in others (37.5%). This may be due to the improved resolution of TEE compared with surface transthoracic echocardiograms. Progression to moderate or more at last follow-up was uncommon (11/73; 15%) and was even less common for a referent surgeon (6%). After 10 years, the 94% of patients with no MR after MV repair progressed to moderate MR (6%) and to moderate to severe MR (1%), whereas the patients with intraoperative mild residual MR (n = 56) progressed to moderate MR (11%; n = 6) and to moderate to severe MR (9%; n = 5).

The need for reoperation in the mild MR group was uncommon. It occurred early in only 2 patients, and in 1 patient we recognized later that SAM was a manifestation of transfusion-related acute lung injury, not of primary valve dysfunction. We identified no clear echocardiographic criteria to predict progression of mild to moderate or more MR, but patients with transiently reduced ejection fraction after surgery were more likely to have MR resolve over time.

Few centers have specifically investigated the effects of residual MR. A report from Australia reported on 685 patients with DMR by a single surgeon over 20 years; repair rates in that series were more than 90%.[9] In this series, 12% of repairs had "more than" none/trivial MR (equivalent to our mild MR group, but potentially including more than mild as well), and 47% of the late MR occurred in those patients. The degree of residual intraoperative MR was a predictor of late moderate or more MR ($P < .001$). Similar to our study, 90% of those with no residual MR on the intraoperative TEE remained free of moderate or

more MR and reoperation in 15 years of follow-up. Unlike in our study, the authors[9] did find an increased risk of developing recurrent MR related to anterior leaflet repair and bileaflet prolapse.

In a small series, Rizza[5] compared 54 patients with no residual MR with 44 patients with "less than moderate (mild and mild to moderate residual)" MR based on post-pump TEE and found a higher rate of progression to severe MR in the less than moderate residual MR group (13.6% vs 3.7%, $P = .016$). Additionally, they reported a higher composite end point of in-hospital death or need for intervention for severe recurrent MR in patients with residual MR (13.6% vs 5.5%). We did not identify a difference in mortality or reoperation. Unlike in our study, the patient population included varied etiologies of MR, not limited to DMR.

Sakaguchi and colleagues[6] compared 12 patients with residual MR with 117 control patients with no residual MR. Residual MR was loosely defined, not judged by echocardiogram alone, and could include significant leakage found by a saline injection test that resulted in conversion to prosthetic valve replacement; MR with maximum regurgitant jet area greater or equal than 1 cm^2 on postpump TEE; or very early (<1 month) recurrence of moderate or greater MR. Patients with residual MR were older, were more likely to have fibroelastic deficiency, and received smaller annuloplasty rings compared with those with no residual MR. Of the 12 patients, 7 required a second pump run for repair and 4 required replacement. Their study did not report long-term outcomes; however, they did assess echocardiographic predictors for the development of residual MR and found the anterior mitral leaflet angle to be significant, which their analysis concluded was influenced by smaller anterior-posterior annular diameter and lower left ventricular ejection fraction.

It has long been known that residual moderate MR indicates a significant risk for reoperation and impaired clinical outcomes[3,4,7]; therefore, we have not accepted that outcome for our patients. Another large series reports excellent repair outcomes, but does not mention residual intraoperative MR assessment or treatment.[10] Castillo and colleagues[11] describe the use of a second run on bypass for any patient with more than trivial MR. Our series included 22 patients who initially had moderate MR but had a second crossclamp to perfect the repair and reduce the MR to no MR in 20 or mild MR in 2 patients. Theoretically, patients with a visible jet outside the coaptation line, such as a leaflet perforation or residual prolapse, may be best served by a re-repair, but our echocardiographic studies were not able to document those types of failure.

Unfortunately, the literature has not been helpful for surgeons deciding how to manage mild residual MR, and we hope our data and analysis will aid those facing the decision whether another crossclamp and re-repair are required.

Study Limitations

This study is limited by its retrospective nature and inherent risk for confounding and bias. We attempted to mitigate this risk by performing a 3-to-1 PS-matched analysis. Although this study captured all consecutive repair operations meeting the inclusion criteria listed earlier, the majority of cases were performed by a single referent surgeon (1037 of the 1155 patients in the entire cohort and 229 of the 267 matched patients). Thus, these results may not apply to most cardiothoracic surgeons.

Intraoperative assessment of residual MR was performed by trained cardiologists and cardiac anesthesiologists and confirmed by the primary surgeon. However, in some cases, few images were saved to allow for in-depth retrospective echocardiographic assessment. Many of the late follow-up echocardiography reports came from outside institutions, and there were no images available for review (Table E1). Because MR is a load-dependent parameter, hypotension or hypovolemia coming off cardiopulmonary bypass may have reduced the apparent severity of MR, although all images were interpreted when the patient was stable and off bypass. Late interpretation of intermediate grades of MV regurgitation was rounded up (ie, mild-moderate = moderate) as per our convention, so that we did not minimize the severity of MR.

CONCLUSIONS

The results of this study highlight the importance of achieving a successful DMR repair. Mild residual MR is uncommon, 6% in this series, and in most patients it resolved or stayed the same over time. Progression to late moderate or more MR was seen in both groups but was more common for those with mild MR. At 10 years, freedom from MV reoperation was very high in both groups: 99.5% in patients with no MR and 96.9% in patients with mild MR. There was no difference in late survival. Surgeon expertise seems to be important to minimize late MR progression. Every effort should be made to perform the perfect repair for each patient. But for those with mild residual MR, results to 10 years indicate that a second crossclamp and attempts at further repair are not necessary for most patients.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/19%20AM/Sunday_May5/1.%20PLENARY/1.%20PLENARY/16h%20-%2018h/P3_3.mp4.

Conflict of Interest Statement
Dr Cox: Atricure consultant, Chairman, Scientific Advisory Board, stockholder. Dr McCarthy: Edwards Lifesciences: consultant and royalties; Abbott: Advisory Board; Atricure: Honorarium Dr Malaisrie: Edwards: speaker and consultant; Abbott: speaker. All other authors have nothing to disclose with regard to commercial support.

References

1. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP III, Guyton RA, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association task force on practice guidelines. *J Thorac Cardiovasc Surg*. 2014; 148:e1-132.
2. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP III, Fleisher LA, et al. 2017 AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with Valvular Heart Disease: A report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines. *Circulation*. 2017;135:e1159-95.
3. Lim E, Ali ZA, Barlow CW, Hosseinpour AR, Wisbey C, Charman SC, et al. Determinants and assessment of regurgitation after mitral valve repair. *J Thorac Cardiovasc Surg*. 2002;124:911-7.
4. Suri RM, Clavel MA, Schaff HV, Michelena HI, Huebner M, Nishimura RA, et al. Effect of recurrent mitral regurgitation following degenerative mitral valve repair: long-term analysis of competing outcomes. *J Am Cardiol*. 2016;67: 488-98.
5. Rizza A, Sulcaj L, Glauber M, Trianni G, Palmieri C, Mariani M, et al. Predictive value of less than moderate residual mitral regurgitation as assessed by transesophageal echocardiography for the short-term outcomes of patients with mitral regurgitation treated with mitral valve repair. *Cardiovasc Ultrasound*. 2007;5:25.
6. Sakaguchi T, Kagiyama N, Toki M, Hiraoka A, Hayashida A, Totsugawa T, et al. Residual mitral regurgitation after repair for posterior leaflet prolapse-importance of preoperative anterior leaflet tethering. *J Am Heart Assoc*. 2018;7.
7. Fix J, Isada L, Cosgrove D, Miller DP, Savage R, Blum J, et al. Do patients with less than 'echo-perfect' results from mitral valve repair by intraoperative echocardiography have a different outcome? *Circulation*. 1993;88:II39-48.
8. Goldstone AB, Cohen JE, Howard JL, Edwards BB, Acker AL, Hiesinger W, et al. A "repair-all" strategy for degenerative mitral valve disease safely minimizes unnecessary replacement. *Ann Thorac Surg*. 2015;99:1983-91.
9. Gardner MA, Hossack KF, Smith IR. Long-term results following repair for degenerative mitral regurgitation - analysis of factors influencing durability. *Heart Lung Circ*. October 17, 2018 [Epub ahead of print.
10. David TE, Armstrong S, McCrindle BW, Manlhiot C. Late outcomes of mitral valve repair for mitral regurgitation due to degenerative disease. *Circulation*. 2013;127:1485-92.
11. Castillo JG, Anyanwu AC, Fuster V, Adams DH. A near 100% repair rate for mitral valve prolapse is achievable in a reference center: implications for future guidelines. *J Thorac Cardiovasc Surg*. 2012;144:308-12.

Key Words: degenerative mitral valve regurgitation, mitral valve repair, residual mitral regurgitation

Discussion

Dr Gilles D. Dreyfus *(Monte Carlo, Monaco)*. We all try our best to avoid residual recurrent MR, and your data show excellent results, as you reached 99.5% freedom from reoperation with no MR and 96.9% with only mild MR at 10 years.

Before getting more into details, I would like to ask you 2 questions. You are reporting your 14-year experience, including 1155 patients, but your median clinical follow-up was 4.7 years and your echo follow-up was a mean of 3.3 years. Can you explain your methodology to reach reliable results in 10 years?

Dr Bartlomiej Imielski *(Chicago, IL)* Although we have not looked at the year-to-year rate of MV repair, we have noticed a trend at Northwestern toward having a higher volume of MV repairs more recently as opposed to before, and this likely reflects local referral patterns.

Dr Dreyfus. My second question refers to postoperative MR quantification. As you know, we all try to stick to quantitative methods to indicate surgery, and unfortunately after all these years we keep referring to 0 to 4+ MR in the postoperative period, which is a mix of semiquantitative and quantitative assessment, which really doesn't make it very precise.

On your central picture from the article and the one you showed displayed on the screen, you had 0 as nontrivial, 1 as mild, then I guess 2+ MR is moderate, so 3+ is what, is moderate severe and 4+ is severe. I would like to know if you do believe that we should agree to use a more precise grading in our follow-up studies as we do currently?

Dr Imielski. I concur in that any standardization and clarification of these criteria would be beneficial. In our center, all of our echocardiograms were performed by our echocardiography trained cardiac anesthesiologists, so that standardizes it within our group. We tried to take a look at the echocardiographic data; however, we had some patients who, of course, were lost to follow-up at other centers, For the remaining, we had reports, we could not review all the imaging, and so at this point I cannot clarify those. But absolutely, more standardized nomenclature would definitely help everybody.

Dr Dreyfus. You think we should use a quantitative method that is applied preoperatively or another one?

Dr Imielski. Dr McCarthy, do we have any input on that?

Dr Patrick M. McCarthy *(Chicago, Ill)*. Gilles, it would be great to get the quantitative data. It's just so hard to get the data from the echocardiographers in the real world, especially when you are looking at trivial and mild MR. The judgment of trivial usually has to be a small jet that doesn't travel beyond the ring, and mild just barely will travel beyond the ring.

Dr Dreyfus. This was not specifically for your study but was generally speaking more broadly to all studies dealing with long-term results with mitral repair.

Now, chasing mild MR is rare, but even more rare is that some MR will disappear with time, and as shown from your

data, in 66 patients with mild residual MR after repair, 24% got better with time and turned to no MR at all. As I have never seen that in such evolution, can you speculate what happened in these patients who I would say by magic got no MR after being graded higher grades before that?

Dr Imielski. I think part of it is when you are coming off pump, you still might not have full recovery of your ejection fraction, and so you might have a bit of residual regurgitation at the line of coaptation. Additionally, when we started reviewing the limited echocardiographic data that we had, we saw that the only signal that tended to show significance was that in patients who had recovery of their ejection fraction, their regurgitation tended to improve. So I think this really means that the patients who undergo remodeling are those who likely will have improvement of their regurgitation with time.

Dr Dreyfus. If we come back to your differences between the no MR group (94%) and mild MR group (6%), you rightly mention emergency as a risk factor but also A3 prolapse. Can you tell us how you fix A3 prolapse in the posterior commissure in your routine practice?

Dr Imielski. For most of our repairs, we tend to perform a posterior leaflet resection, which may unmask a small jet at the interleaflet commissure, which in turn may require a simple stitch to close this.

Dr McCarthy. For the A3 prolapse, it typically would be a little magic stitch, 1 or 2. Occasionally, someone might have a small resection or an imbrication of A3, occasionally chord transfers. We have a variety of the usual techniques.

Dr Dreyfus. As you know, residual MR within the closure line is more difficult to address than those within the leaflets or at the annular level. In the 6% of 73 patients with mild MR, were you able to even retrospectively segregate residual regurgitation location within the line of coaptation—and, by the way, do you have the data about your coaptation height after weaning from bypass—or outside the closure line within the leaflet itself or at the annular level, and did you find a predominant location for mild MR?

Dr Imielski. The main limitation to reporting on the entire cohort for this was that long-term echocardiographic data were not complete, especially with some patients lost to other centers. Twenty patients in our series initially had greater than mild regurgitation, which was re-repaired, and they were in the no or trivial regurgitation group afterward.

In general, we believe that mild residual MR that comes from the coaptation line is the type that can be safely left and less likely to progress. We have certain tricks that we use to ensure that this is the case. For example, when using bulb insufflation, we mark the line of coaptation so that when the valve deflates and the ventricle deflates, you can measure and see how much coaptation you have left to ensure that it is actually a reasonable amount. Do you mind repeating the second portion of that?

Dr Dreyfus. Basically, were you able to localize where your mild MR was coming from, mostly from the closure line or from inside, either repair of suture leaflets or at the annular level?

Dr Imielski. Unfortunately, we were not able to because of lack of full echocardiographic data. There was 1 patient of those 2 who underwent early reoperation, and that was due to a leaflet perforation, and that happened on postoperative day 6.

Dr Dreyfus. To clarify for the audience, you are in the resect or the respect group?

Dr Imielski. In general, I would say that we definitely tend to do a resection with an annuloplasty ring.

Dr Dreyfus. So basically we can go home saying that we should not worry about mild MR because overall, this will resolve in 43% and 37% will remain the same. So I think it's a great message, and we have to fight against moderate MR during the surgery.

Dr Richard J. Shemin *(Los Angeles, Calif)*. My question is focused on the intraoperative TEE measurement. We know the impact of anesthesia coming off bypass; volume afterload can affect that result. Obviously, you must have a strict protocol of how you adjust the hemodynamics to be able to get a good intraoperative evaluation. Can you share that with us?

Dr Imielski. I am going to ask Dr McCarthy to just further clarify.

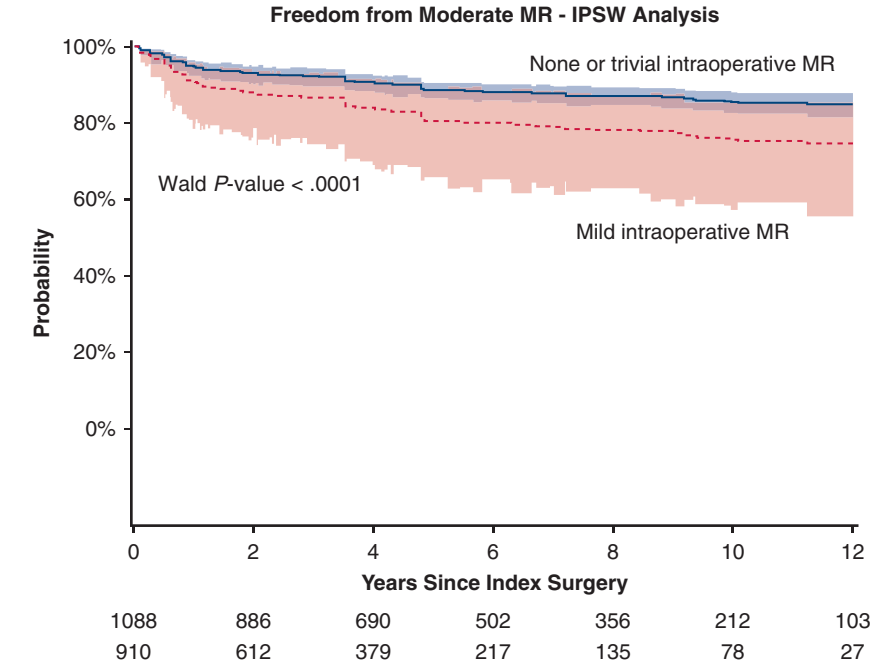
Dr McCarthy. The next article is on exactly that algorithm.

Dr Shemin. Do you also do a predischarge echo?

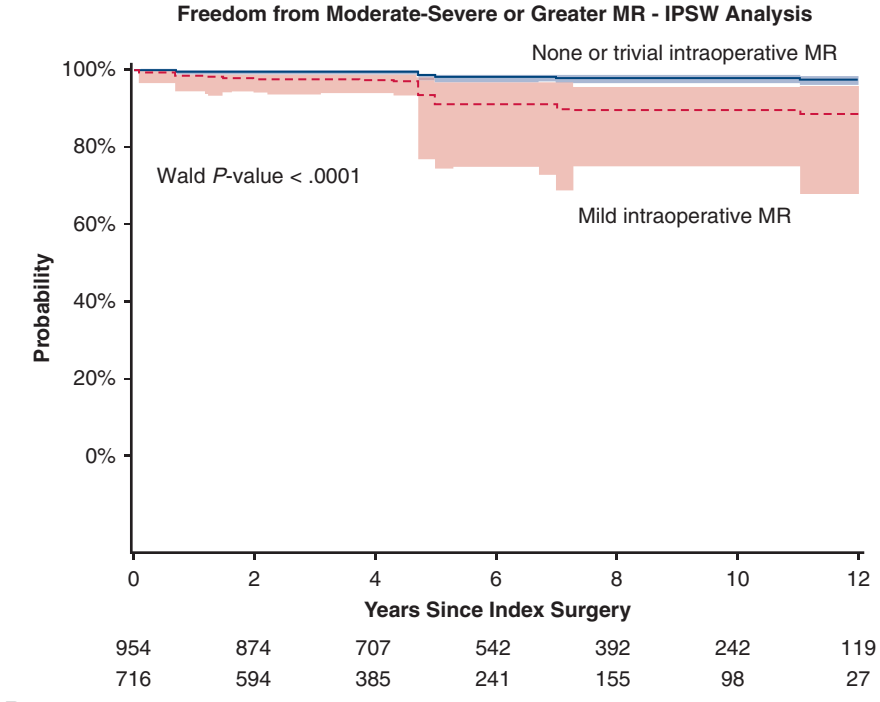
Dr McCarthy. Yes, everyone gets a predischarge echo on day 3. It's our routine and always has been.

Dr Shemin. And the concordance between the 2 are good?

Dr McCarthy. Actually, it has been very high. We still see quite a few patients who are downgraded, but they are going from transesophageal to transthoracic. But another aspect is that patients who come off pump may have somewhat reduced contractility and ejection fraction. As this improves, they get better coaptation of the leaflets. Our echocardiographers thought that change may explain the reduction in MR.

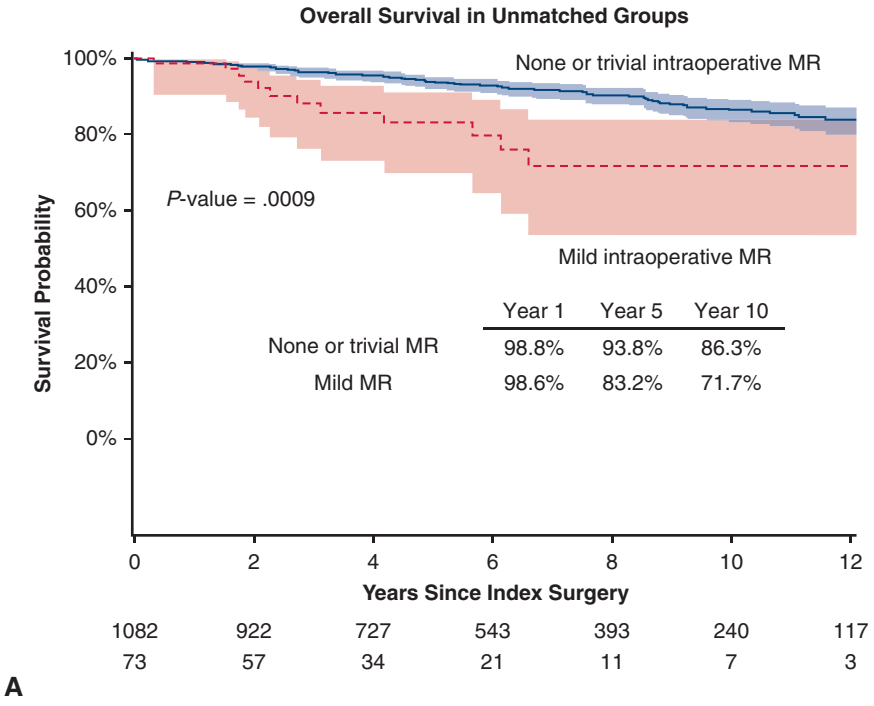


A

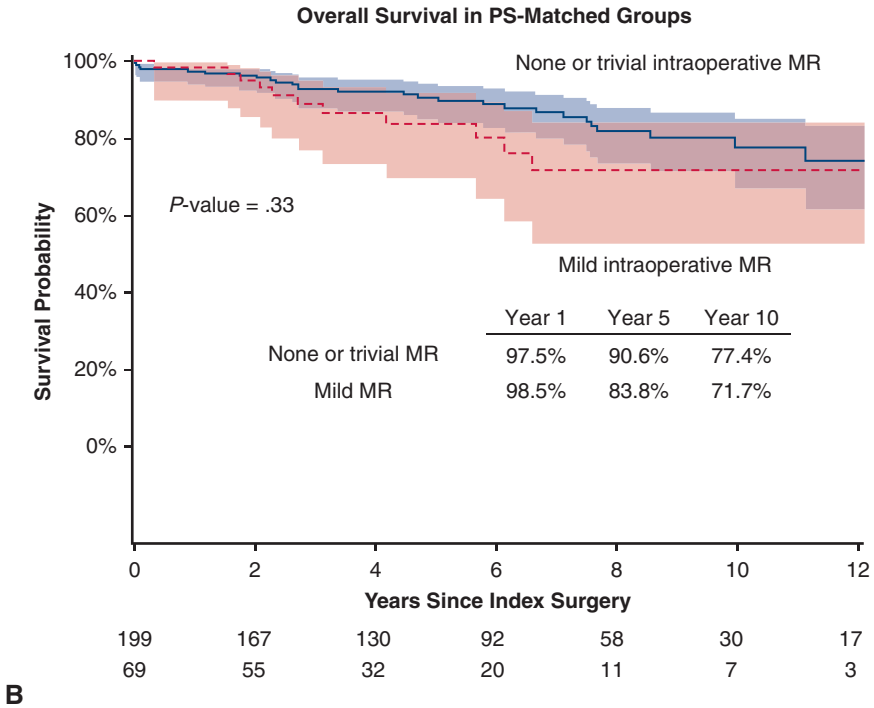


B

FIGURE E1. A, Freedom from moderate MR. B, Freedom from moderate-severe or greater MR at any time during follow-up based on an inverse PS weighted approach. *MR*, Mitral regurgitation; *IPSW*, inverse propensity score weighted.



A



B

FIGURE E2. Kaplan–Meier overall survival *curves* in the unmatched (A) and PS-matched groups (B). *MR*, Mitral regurgitation; *PS*, propensity score.

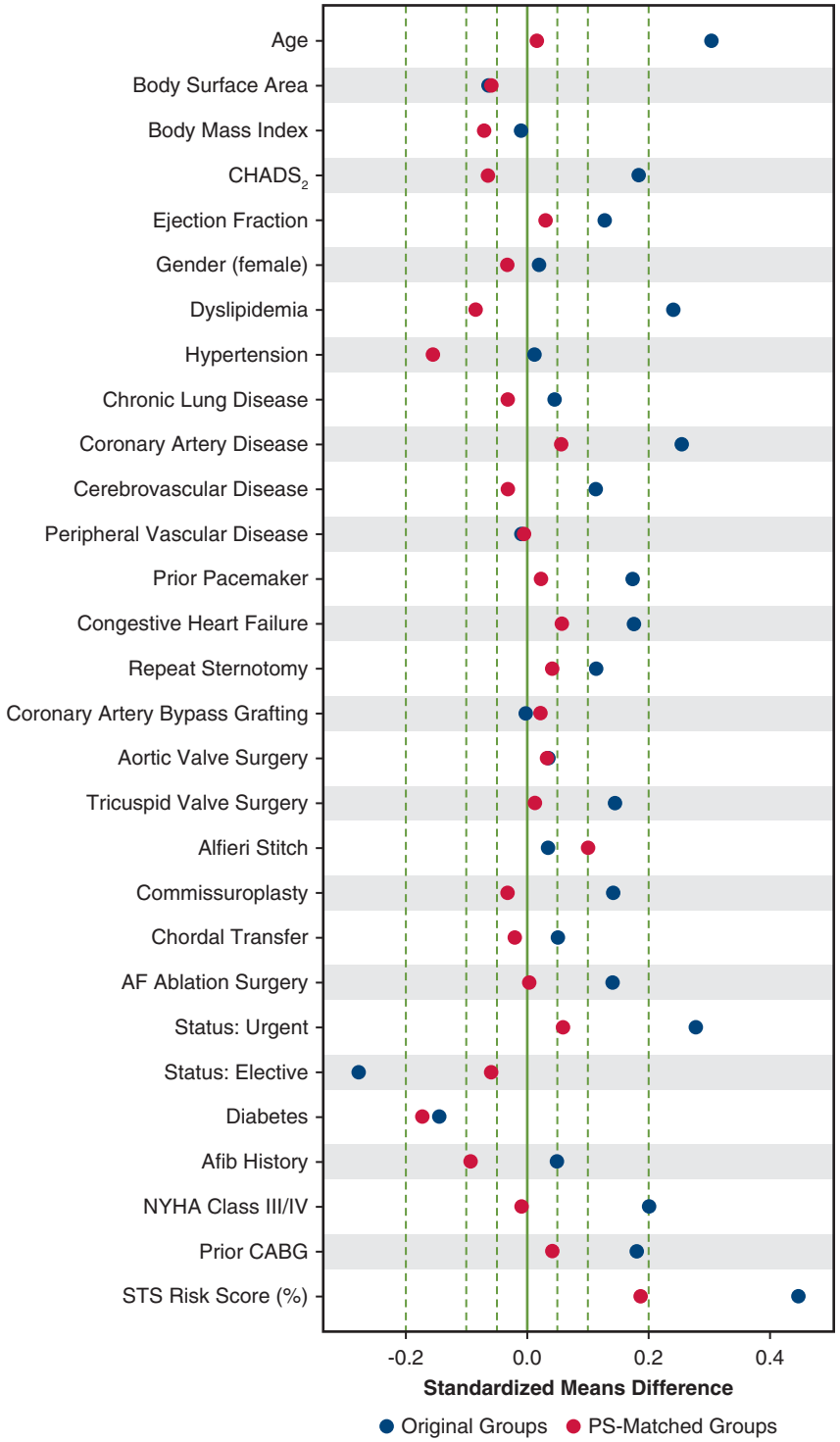


FIGURE E3. *Dot plots* of standardized mean differences before and after PS matching, indicating that adequate covariate balance is observed after matching (standardized mean differences are < 0.2 in absolute value). *PS*, Propensity score; *$CHADS_2$*, Congestive heart failure, Hypertension, Age 75 years or older, Diabetes mellitus, Stroke or transient ischemic attack; *AF*, atrial fibrillation; *NYHA*, New York Heart Association; *CABG*, coronary artery bypass grafting; *STS*, Society of Thoracic Surgeons.

TABLE E1. Number of patients with postdischarge echocardiograms at 1, 5, 10, and years

Time point	Patients with postdischarge echocardiograms
1 y (6-18 mo)	675
5 y (54-66 mo)	211
10 y (114-126 mo)	58