Elevated gradient after mitral valve repair: The effect of surgical technique and relevance of postoperative atrial fibrillation

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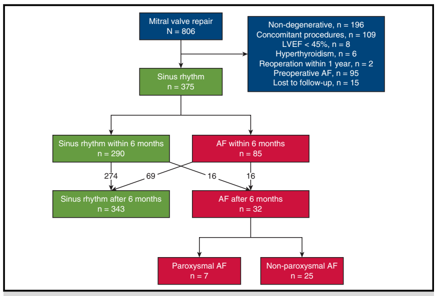
ABSTRACT

Objectives: We sought to investigate the effect of surgical technique in mitral valve repair on postoperative transmitral gradient (PTMG) and the relationship between PTMG and postoperative atrial fibrillation (AF).

Methods: In this retrospective study, 390 patients who underwent mitral valve repair for degenerative mitral regurgitation without AF were included. PTMG was measured using transthoracic echocardiography before patient discharge. At follow-up, occurrences of AF within 6 months of surgery (early AF) and 6 months after surgery (late AF), as well as clinical and echocardiographic data were documented and investigated.

Results: The in-hospital mortality was 0, and the mean gradient was 3.1 ± 1.2 mm Hg before patient discharge. The risks for higher PTMG included cleft closure, edge-to-edge technique, full ring annuloplasty, and smaller indexed prosthetic size ($P < .05$ for all). After a median follow-up of 46 months, stable sinus rhythm was maintained in 73.1% of the overall cohort and early AF occurred in 22.7% of patients. A total of 32 patients (8.5%) had late AF, which was significantly associated with PTMG (odds ratio, 3.93; $P = .004$). The minimum P value approach identified a mean gradient of ≥4.5 mm Hg as the best threshold for predicting late AF ($\chi^2 = 40.704$; $P < .001$).

Conclusions: Patients who undergo mitral valve repair for degenerative mitral insufficiency might benefit from modification of the existing leaflet repair and annuloplasty techniques to achieve a lower PTMG level, which is associated with a decreased incidence of late AF during midterm follow-up. (J Thorac Cardiovasc Surg 2019;157:921-27)



Rhythm outcomes after mitral valve repair for degenerative mitral regurgitation.

Central Message

Affected by leaflet repair and annuloplasty, a transmitral gradient >4.5 mm Hg is associated with postoperative atrial fibrillation.

Perspective

With advances in mitral valve repair techniques, a reduced orifice area and an elevated gradient have become a matter of concern. In this study we verified the relationship between transmitral gradient and atrial fibrillation during midterm follow-up. Our findings may be applied in further modification of repair techniques, namely calculating the minimum ring size on the basis of orifice area before surgery.

See Commentaries on pages 928 and 930.

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Mitral valve repair is a standard procedure in treatment of significant degenerative mitral regurgitation (MR), with better survival rates and cardiac reverse remodeling compared with valve replacement.[1] Although numerous studies have extensively investigated the risks for mortality, morbidity, and durability of repair after surgery, reports regarding the effect of postoperative transmitral gradient (PTMG) on clinical

Scanning this QR code will take you to the article title page to access supplementary information.

Abbreviations and Acronyms

- AF = atrial fibrillation
- CI = confidence interval
- LVEF = left ventricular ejection fraction
- MG = mean gradient
- MR = mitral regurgitation
- OR = odds ratio
- PTMG = postoperative transmitral gradient
- TEE = transesophageal echocardiography

outcomes are less frequent. Chan and colleagues reported that a mean gradient (MG) >3 mm Hg was associated with lower exercise capacity and worse quality of life.[2] Incidence of adverse events, namely atrial fibrillation (AF), might also be increased by an elevated PTMG. However, this relationship and an appropriate threshold of PTMG predictive of postoperative AF have not been studied. Therefore, the aims of this study were to identify surgical techniques that lead to an elevated PTMG after mitral valve repair and to evaluate the relevance of PTMG in patients with postoperative AF during follow-up.

METHODS

Patient Selection

The study was reviewed by the Ethics Committee of Patients of Shanghai Chest Hospital. The requirement for informed consent was waived because of the retrospective nature of the study (date and number of institutional review board approval: January 18, 2018; KY18003). Between January 2006 and January 2016, 806 consecutive patients at our institution underwent a surgical mitral valve repair for significant MR. Exclusion criteria were as follows: (1) nondegenerative MR, including rheumatic, ischemic, congenital, or infective MR (n = 196); (2) concomitant other valve replacement, aortic surgery, or coronary artery bypass grafting (n = 109); (3) left ventricular ejection fraction (LVEF) <45% to exclude the combined functional mitral pathology (n = 8); (4) hyperthyroidism (n = 6); (5) mitral valve reoperation within 1 year because of surgical failure (n = 2); and (6) preoperative AF, including paroxysmal, persistent, and long-persistent AF (n = 95). After screening, 390 patients were included in this study. The patient characteristics and operative data of the overall cohort are shown in Table 1.

TABLE 1. Baseline characteristics (overall cohort, N = 390)

Characteristic	Value
Age, y	52.7 ± 12.2
Male sex	251 (64.4)
Body surface area, m^2	1.67 ± 0.23
NYHA functional class III to IV	148 (37.9)
Comorbidities	
Hypertension	115 (29.5)
Diabetes mellitus	18 (4.6)
Coronary artery disease	32 (8.2)
Chronic obstructive pulmonary disease	4 (1.0)
Chronic kidney disease	3 (0.8)
History of stroke	7 (1.8)
Transthoracic echocardiography	
Left atrial diameter, mm	43.7 ± 6.6
Left ventricular end-systolic diameter, mm	33.9 ± 5.3
Left ventricular end-diastolic diameter, mm	57.0 ± 6.6
LVEF, %	63.7 ± 4.4
Systolic pulmonary artery pressure, mm Hg	44.3 ± 14.6

Continuous variables are presented as mean ± SD and categorical variables as n (%). *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction.

Surgical Techniques and Perioperative Management

Operations were performed through a median sternotomy (n = 351), a ministernotomy (n = 11), or a right minithoracotomy (n = 28), with the use of mild hypothermic cardiopulmonary bypass and intermittent antegrade cold blood cardioplegia. The structural characteristics of the entire mitral complex and its pathology were identified using nerve hooks and saline injections. The choice of repair technique was determined according to the surgeon's preference. The details of the leaflet repair techniques used in the cohort, including leaflet resection (quadrangular or triangular), neochordal replacement (including loop-in-loop technique), edge-to-edge technique, commissuroplasty, and leaflet plication, were described in our previous work.[3] In the present study's cohort, 4 types of annuloplasty rings were implanted: 2 flexible C-shape bands (Cosgrove band from Edwards Lifesciences, Irving, Calif, and Sovering band from Sorin Biomedica Cardio S.r.l., Saluggia, Italy) and 2 semirigid full rings (Carpentier-Edwards Physio I ring from Edwards Lifesciences and Sorin Memo-3D ring from Sorin Biomedica Cardio S.r.l.). The choice of prosthetic type was according to the surgeon's preference. The prosthetic size was determined according to the measurement of intertrigonal distance or anterior leaflet area. Postbypass transesophageal echocardiography (TEE) was not performed until mean arterial pressure reached 75 mm Hg with adequate left ventricular filling. A second repair attempt was considered if TEE detected greater than a mild degree of residual MR, mitral stenosis (MG >6 mm Hg), or systolic anterior motion that could not be resolved by discontinuation of inotropic agents, heart rate control, and volume management.[4] Concomitant procedures were limited to tricuspid ring annuloplasty (n = 61).

The heart rhythm of each patient was monitored continuously from postoperative day 0 until patient discharge using telemetry or a monitoring device. Whenever a period of AF or atrial flutter that lasted more than 30 seconds was noted by either the nursing staff or the monitoring device, the operating surgeon or a physician on-call would be informed. The data on episodes of AF or atrial flutter and their treatment, including use of class I and/or III antiarrhythmic drugs, β-blockers, calcium channel blockers, and electrical cardioversion, were collected by reviewing records of daily rounds, order lists, and nursing notes. Unless contraindicated, patients with perioperative AF were discharged with warfarin and class I or III antiarrhythmic drugs. Typically, we did not use prophylactic antiarrhythmic drugs for patients without AF before discharge. β-Blockers or calcium channel blockers were not considered to be antiarrhythmic drugs.

Transthoracic echocardiography was performed on all subjects before discharge. MGs were calculated using the modified Bernoulli equation at a heart rate ranging from 50 to 100 beats per minute. Echocardiograms performed during tachycardia were excluded from analysis.

Follow-up

Routine follow-up included an electrocardiogram, 24-hour Holter monitoring, or pacemaker interrogation, and was performed at the discretion of the operating surgeon or referring cardiologist. Specifically, electrocardiogram or pacemaker interrogation was routinely performed at 3, 6, and 12 months after surgery, and yearly thereafter. Patients with early AF and those who complained of paroxysmal/continuous palpitations received 24-hour Holter monitoring. Holter monitoring was repeated if the complaints persisted, even if previous reports were normal. Antiarrhythmic drugs and warfarin were withdrawn 6 months after surgery, provided sinus rhythm was restored. Electrical cardioversion and transcatheter ablation were considered in patients with AF beyond the first 6 months after surgery. Practices of clinical evaluation, rhythm monitoring, and medical/interventional management of AF were on the basis of the current guidelines.[5] Moreover, clinical cardiac function, degree of residual MR, MG, and other echocardiographic parameters were also evaluated during outpatient visits. The echocardiographic data before discharge and during follow-up are listed in Table 2.

End Points

In this study, early AF was defined as occurrence of AF or atrial flutter >30 seconds within 6 months after surgery (from postoperative day 0 to day 180), assessed using telemetry throughout hospitalization, electrocardiogram, 24-hour Holter monitoring, or pacemaker interrogation. Similarly, AF or atrial flutter that occurred or lasted beyond the first 6 months after surgery was considered late AF. The patients with no sign of early or late AF throughout the duration of their follow-up were considered to be in stable sinus rhythm. The end points of this study were all-cause mortality and incidence of early and late AF.

Statistical Analysis

Continuous variables are presented as mean ± SD and were compared using the Student *t* test or Mann–Whitney *U* test. Categorical variables are presented as numbers and percentages and were compared using the χ^2 test or Fisher exact test. The Kaplan–Meier technique was used to evaluate 5-year survival.

Using empirical evidence, we hypothesized that an optimal MG after mitral valve repair should be no higher than 3 mm Hg.[2] On the basis of that premise, the forward stepwise multivariate logistic regression models were used to identify significant factors that led to MG >3 mm Hg ($P_{entry} = .05$, $P_{stay} = .05$). The following preoperative and operative covariates were included in the model: age older than 65 years, sex, operating surgeon, left atrial diameter, left ventricular end-systolic and end-diastolic diameters, LVEF, type of incision, location of degenerative lesion, leaflet resection, quadrangular resection, sliding technique, neochordal replacement, loop-in-loop technique, edge-to-edge technique, commissuroplasty, leaflet plication, type of annuloplasty ring, indexed prosthetic size, and tricuspid annuloplasty. The final model's goodness of fit was assessed with the Hosmer–Lemeshow statistic. Similarly, apart from the aforementioned covariates, baseline comorbidities, New York Heart Association functional class, medications at discharge, postoperative echocardiographic parameters, and cardiac rhythm were also entered into multivariate logistic regression models to determine independent predictors for early and late AF. Additionally, a minimum *P* value approach was used for the threshold value of MG that independently predicted the incidence of late AF.[6] In this approach, the dichotomization of MG was performed at an interval of 0.5 mm Hg. Each time, a 2 × 2 contingency table with late AF and dichotomized MG was created (eg, <2 mm Hg vs ≥2 mm Hg; <2.5 mm Hg vs ≥2.5 mm Hg, etc). The cutoff value for MG that had the maximum χ^2 statistic was selected as the threshold that best predicted late AF. Finally, a threshold of indexed orifice area of full annuloplasty ring for predicting the MG threshold for late AF was calculated in a similar manner, using an interval of 0.25 cm^2/m^2 for dichotomization. Areas of C-shape bands were unavailable because of their open structure. In this study, prosthetic sizes and orifice areas were indexed according to body surface area.

A 2-tailed *P* value < .05 was considered statistically significant. All statistical analyses were performed using SAS version 9.2 (IBM Corp, Armonk, NY) and OriginPro 2018 (OriginLab, Northampton, Mass) software.

RESULTS

Patient Characteristics and Perioperative Data

The mean age was 52.7 ± 12.2 years, with a male predominance (64.4%) in the overall cohort. A total of 148 patients (37.9%) were designated as New York Heart Association functional class III-IV.

The mean cardiopulmonary bypass and aortic cross-clamp times were 119.7 ± 35.9 minutes and 80.6 ± 24.7 minutes, respectively. Anterior leaflet prolapse was identified in 87 patients, posterior leaflet prolapse in 257 patients, bileaflet prolapse in 25 patients, and commissural prolapse in 20 patients. Clefts that involved anterior or posterior leaflet were identified and closed in 21 patients. Neochordal replacement was used in 149 patients, including the loop-in-loop technique in 26 patients. Leaflet resection was performed in 145 patients, with quadrangular resection in 50 patients, triangular resection in 95 patients, and the sliding technique in 8 patients. The edge-to-edge technique was performed in 44 patients, commissuroplasty in 64 patients, and leaflet plication in 22 patients. C-shape annuloplasty bands were implanted in 133 patients and full rings in 257 patients. The mean prosthetic size was 29.1 ± 2.1 mm. After standardization according to body surface area, the mean indexed prosthetic size was 17.3 ± 2.0 mm/m^2. The post bypass TEE showed that 3 patients had persistent systolic anterior motion and 5 patients had moderate residual MR. These 8 patients underwent reinstituted cardiopulmonary bypass and a successful second repair.

The operative mortality was 0%. Postoperative morbidities included low cardiac output syndrome (n = 9), acute kidney failure (n = 2), ventilation support >72 hours (n = 5), reoperation for bleeding (n = 6), and total atrioventricular block requiring pacemaker implantation (n = 2).

TABLE 2. Transthoracic echocardiography before discharge and at early and late follow-ups

Characteristic	Before discharge (N = 390)	At 6-month follow-up (n = 375)	At late follow-up (n = 375)
Residual MR			
None	197 (50.5)	148 (39.5)	127 (33.9)
Trivial	159 (40.8)	156 (41.6)	165 (44.0)
Mild	34 (8.7)	66 (17.6)	61 (16.3)
Moderate or severe	0 (0)	5 (1.3)	22 (5.9)
MG, mm Hg	3.1 ± 1.2	3.3 ± 1.2	3.3 ± 1.4
Left atrial diameter, mm	36.1 ± 5.7	38.1 ± 7.2	38.9 ± 6.2
Left ventricular end-systolic diameter, mm	31.6 ± 5.9	31.0 ± 5.1	30.7 ± 5.8
Left ventricular end-diastolic diameter, mm	48.9 ± 6.0	49.3 ± 5.4	48.7 ± 5.4
LVEF, %	59.8 ± 5.7	60.7 ± 5.1	61.8 ± 5.5
Systolic pulmonary artery pressure, mm Hg	33.3 ± 5.3	36.1 ± 8.6	36.8 ± 10.1
Tricuspid regurgitation, degree	1.0 ± 0.8	1.0 ± 0.8	1.1 ± 0.9

Continuous variables are presented as mean ± SD and categorical variables as n (%). *MR*, Mitral regurgitation; *MG*, mean gradient; *LVEF*, left ventricular ejection fraction.

A total of 86 patients were discharged with antiarrhythmic drugs (amiodarone for 84 patients and propafenone for 2 patients). β-Blockers were prescribed for 213 patients (54.6%) and calcium channel blockers for 30 patients (7.7%).

Multivariate logistic models showed that cleft closure (odds ratio [OR], 6.81; 95% confidence interval [CI], 1.45-31.92; P = .015), edge-to-edge technique (OR, 2.34; 95% CI, 1.04-5.28; P = .040), ring annuloplasty (OR, 2.78; 95% CI, 1.59-4.76; P < .001), and indexed prosthetic size (OR, 0.78; 95% CI, 0.68-0.89; P < .001) were independent factors affecting PTMG.

Surgical and Rhythm Outcomes

Fifteen patients (3.8%) were lost to follow-up. The median follow-up time was 46 months (ranging from 9 to 136 months). The 5-year all-cause mortality was 3.8% (n = 6, Figure E1). Among them, 1 patient died of end-stage heart failure, 2 patients died of cerebrovascular events, and 3 patients died of noncardiac causes. Mitral valve reoperations were performed in 2 patients, because 1 patient had severe MR, and the other had mitral stenosis with MG of 9.7 mm Hg before reoperation.

Rhythm outcomes are shown in Figure 1. Freedom from postoperative AF and atrial flutter was achieved in 274 patients (73.1%). Early AF occurred in 85 patients (22.7%), in whom paroxysmal AF was the major form of AF (81.2%). The rate of late AF was 8.5% (32/375), and a non-paroxysmal AF predominance was observed in patients with late AF (78.1%). Moderate to severe MR was present in 4 of 32 (12.5%) patients with late AF versus 18 of 343 (5.2%) patients without late AF. This difference was not statistically significant (P = .095). Ten patients underwent electrical cardioversion and 6 underwent ≥1 transcatheter ablation procedures after 6 months after surgery. Pacemakers were implanted in 2 patients during follow-up.

Multivariate logistic analysis showed that preoperative left atrial diameter (OR, 1.03; 95% CI, 1.00-1.05; P = .025) was the only important factor for early AF after mitral valve repair (Table E1). Age older than 65 years (OR, 2.16; 95% CI, 1.01-5.33; P = .039), PTMG >3 mm Hg (OR, 3.93; 95% CI, 1.55-9.96; P = .004), and early AF (OR, 4.12; 95% CI, 1.94-8.93; P < .001) were identified as important risk factors for late AF (Table E2). Taking into account the maximum χ^2 and the minimum P values, the cutoff MG of 4.5 mm Hg was identified as the best threshold to predict late AF after mitral valve repair (χ^2 = 40.704; P < .001; Table 3). There was no significant difference in age between patients exhibiting MGs < 4.5 mm Hg (n = 325) and those with MGs ≥ 4.5 mm Hg (n = 50; P = .498). The orifice areas of full annuloplasty rings are listed in Table 4.[7,8] The indexed full ring orifice area

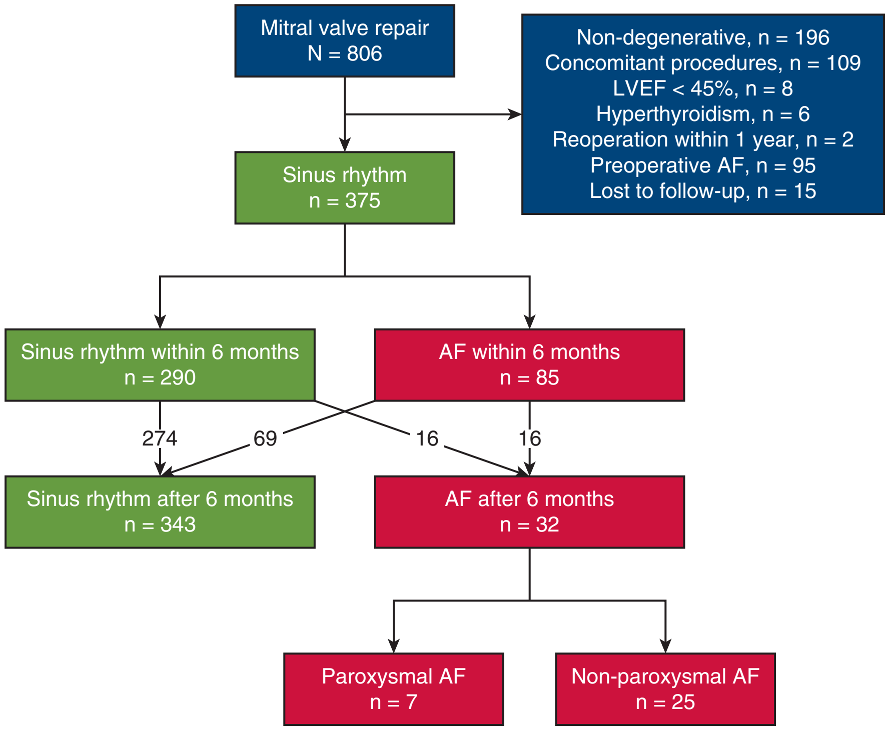


FIGURE 1. Rhythm outcomes for patients undergoing mitral valve repair without preoperative atrial fibrillation. *LVEF*, Left ventricular ejection fraction; *AF*, atrial fibrillation.

TABLE 3. The minimum *P* value approach for threshold of postoperative mean transmitral gradient for late atrial fibrillation

Cutoff, mm Hg	χ^2	*P* value
2	3.042	.081
2.5	9.568	.002
3	9.233	.002
3.5	8.728	.003
4	16.438	<.001
4.5	**40.704**	**<.001**
5	17.131	<.001
5.5	2.632	.105
6	0.763	.383

Data in bold indicate the optimum cutoff with the minimum *P* value.

$\leq$2 cm^2/m^2 was identified as the best threshold for predicting postoperative MG $\geq$ 4.5 mm Hg (χ^2 = 25.984; $P < .001$; Table 5; Video 1).

DISCUSSION

Initiated by Carpentier's French correction in 1983, mitral valve repair has been accepted as the optimal surgery to treat degenerative MR by most surgeons.[8,9] The concepts of degenerative MR repair have also been developing from leaflet resection to "respect rather than resect" approaches, aiming to preserve mitral valve area and facilitate cardiac reverse remodeling.[10-12] Although previous studies have investigated the repair durability and clinical outcomes after repair of degenerative MR, less is known about the postoperative adverse effects, namely elevated PTMGs and occurrence of postoperative AF. Roberts and colleagues reported a high prevalence (55.2%) of elevated PTMGs in patients who underwent mitral valve replacement after previous repair attempts.[13] Furthermore, lower exercise capacity was observed in patients who underwent mitral valve repair for degenerative MR with MG >3 mm Hg,[2] although the effect of surgical technique on PTMG and the potential relationship between PTMG and postoperative AF have not been verified. According to our results, using cleft closure, edge-to-edge technique, semi-rigid full rings, and smaller prosthetic size could lead to an elevated PTMG. Moreover, MG $\geq$4.5 mm Hg induced by an indexed full ring orifice area <2 cm^2/m^2 was associated with a remarkably higher risk of late AF.

In this study, the mean postoperative MG of 3.1 mm Hg was comparable with those in previous studies.[14] Moreover, the mean prosthetic size of 29.1, despite being seemingly smaller than those in previous studies, became acceptable after being indexed by the relatively small body surface areas. Our results were consistent with previous studies, in which full ring annuloplasty and smaller prosthetic size were associated with elevated PTMGs.[15,16] In addition, the edge-to-edge technique might lead to a higher level of PTMG, consistent with previous work.[17,18] However, Alfieri and colleagues, the pioneers introducing the concept of the edge-to-edge technique, did not report PTMG or rate of postoperative AF in their recent investigations of patients who underwent this procedure for degenerative MR. Instead, they simply stated that "clinically relevant mitral stenosis was never detected."[19,20] Leaflet clefts, either on the anterior or posterior leaflet, were routinely closed with 5-0 polypropylene sutures. However, the cleft edges could have been fibrotic and thickened, especially in those with extension to the mitral annulus.[21] In this regard, direct cleft closure could result in poor leaflet mobility, smaller effective orifice area, and higher gradient. Other potential factors, including quadrangular leaflet resection, were of less significance in determining PTMG. We extrapolated that it was the small annuloplasty ring implanted after over-resection of the posterior leaflet rather than the technique itself that had a major effect on elevation of PTMG. Triangular resection and neochordal replacement might be more appropriate alternatives to allow for larger annuloplasty rings.

New-onset AF has been reported to be associated with long-term mortality after mitral valve surgery.[22] However, the course of AF after mitral valve repair has been rarely discussed. In this study, nearly one-quarter of the cohort had early AF, whereas only 8.5% had late AF. Moreover, PTMG was found to be associated with late AF, but not with early AF. These phenomena can be explained by an underlying mechanism, where an increase in left atrial afterload that undermines left atrial reverse remodeling might predispose to AF at a slow rate. On the contrary, early AF might be transient and more affected by the preoperative left atrial diameter, the surgery itself, and the perioperative management, which explains why paroxysmal AF was significantly more common in patients with early AF compared with those with late AF (81.2% vs 21.9%; $P < .001$).

In this study, the best MG threshold for predicting late AF was 4.5 mm Hg, and a total of 50 patients (13.3%) were beyond this threshold. However, it is noteworthy that MG $\geq$2.5 mm Hg was the smallest cutoff that reached statistical

TABLE 4. Prosthetic orifice areas of full annuloplasty rings (N = 257)

Brand	26 mm	28 mm	30 mm	32 mm	34 mm	Reference
Physio I, cm^2	3.25 (13)	3.80 (70)	4.40 (20)	5.04 (8)	5.72 (0)	7
Memo-3D, cm^2	2.78 (6)	3.28 (27)	3.78 (51)	4.39 (41)	4.98 (21)	8

Data are presented as n (%). Carpentier-Edwards Physio I ring from Edwards Lifesciences, Irving, Calif, and Sorin Memo-3D ring from Sorin Biomedica Cardio S.r.l., Saluggia, Italy.

TABLE 5. The minimum *P* value approach for threshold of indexed orifice area of full annuloplasty ring for postoperative mean transmitral gradient ≥4.5 mm Hg

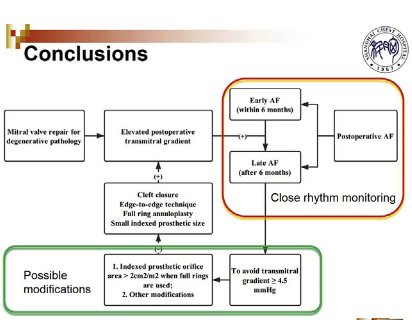
Cutoff, cm^2/m^2	χ^2	*P* value
1.75	0.252	.617
2.00	**25.984**	**<.001**
2.25	4.742	.029
2.50	1.710	.191
2.75	2.430	.119
3.00	1.303	.254
3.25	0.769	.381
3.50	0.508	.476

Data in bold indicate the optimum cutoff with the minimum *P* value.

significance, with a higher sensitivity but a much lower specificity compared with the threshold. In other words, absence of late AF cannot be guaranteed in patients with postoperative MG <4.5 mm Hg. Careful follow-up using Holter monitoring should be considered in patients with an elevated PTMG for early detection and management of AF.

According to our results and the data provided by manufacturers of annuloplasty rings, in patients with an average body surface area of 1.79 m^2,[23] implantation of a 26-mm Physio I ring (Edwards) or a 28 mm Memo-3D ring (Sorin Biomedica Cardio S.r.l.) might lead to an MG ≥4.5 mm Hg and thereby a higher risk of late AF. Furthermore, a 28- to 30-mm Physio I ring (Edwards) and a 30- to 32-mm Memo-3D ring (Sorin Biomedica Cardio S.r.l.) might fail to preserve adequate orifice area, if a cleft is to be closed or the edge-to-edge technique is to be used. Future studies are warranted to investigate the dynamic balance between leaflet repair techniques and optimal prosthetic sizes.

This study is subject to the limitations inherent in retrospective, single-center data studies. Patients with previously undetected paroxysmal AF might not have been effectively excluded from the study, and parameters reflecting atrial volume and function have not been routinely performed at our institution over the past decade. Furthermore, despite the moderate size of the cohort, the incidence of late AF was relatively low, which might undermine the power of statistical analysis. To address this, intergroup χ^2 comparisons using different MG cutoffs were performed, and were favorably consistent with the results of the multivariate models. Finally, the measurement of PTMG might be biased by patients' heart rate and volume status. Nevertheless, our observations provided a clear course of heart rhythm outcomes after mitral valve repair for degenerative MR and validated the relationship between late AF and PTMG.



VIDEO 1. The first author Dr Ma presenting the background and clinical relevance of the study. Video available at: https://www.jtcvs.org/article/S0022-5223(18)32470-X/fulltext.

CONCLUSIONS

Patients who undergo mitral valve repair for degenerative mitral insufficiency might benefit from modifications of the existing leaflet repair and annuloplasty techniques for a lower PTMG level, which is associated with a decreased incidence of late AF during follow-up. Calculating the minimum ring size on the basis of indexed prosthetic orifice area may be considered before surgery.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: mitral valve repair, degenerative mitral regurgitation, atrial fibrillation

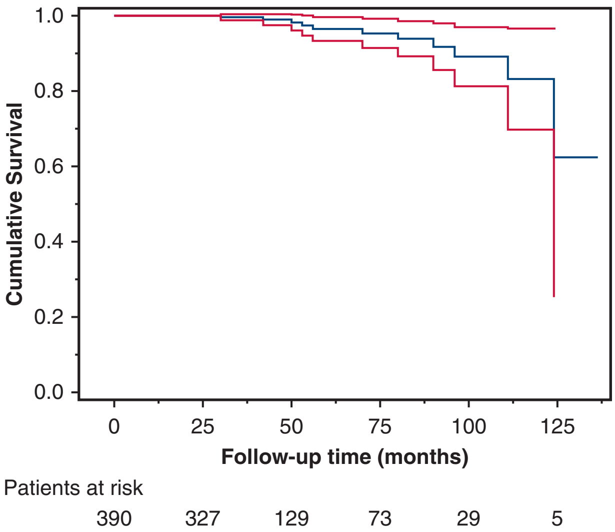

FIGURE E1. The Kaplan–Meier survival curve (*blue line*) and its 95% confidence limits (*red lines*).

TABLE E1. Variable selection in the stepwise logistic model for investigating risk factors for early AF

Step 0 variables		Variables in the final model		
Variables	***P* value**	**Variable**	**OR (95% CI)**	***P* value**
Age older than 65 y	.304			
Male sex	.472			
Surgeon	.885			
Hypertension	.161			
Diabetes mellitus	.942			
Coronary artery disease	.372			
Chronic obstructive pulmonary disease	.254			
Chronic kidney disease	.599			
History of stroke	.254			
NYHA functional class III to IV	.235			
Left atrial diameter	.025	Left atrial diameter	1.03 (1.00-1.05)	.025
Left ventricular end-systolic diameter	.927			
Left ventricular end-diastolic diameter	.601			
LVEF	.297			
Minimally invasive	.083			
Location of degenerative lesion	.266			
Cleft closure	.775			
Leaflet resection	.454			
Quadrangular resection	.880			
Sliding technique	.104			
Neochordal replacement	.144			
Loop-in-loop technique	.122			
Edge-to-edge technique	.162			
Commissuroplasty	.220			
Leaflet plication	.836			
Full annuloplasty ring	.097			
Indexed prosthetic size	.266			
Tricuspid annuloplasty	.390			
Postoperative left atrial diameter	.458			
Postoperative left ventricular end-systolic diameter	.746			
Postoperative left ventricular end-diastolic diameter	.262			
Postoperative LVEF	.343			
Postoperative MR	.852			
PTMG	.283			

OR, Odds ratio; *CI*, confidence interval; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *MR*, mitral regurgitation; *PTMG*, postoperative transmitral gradient.

TABLE E2. Variable selection in the stepwise logistic model for investigating risk factors for late AF

Step 0 variables		Variables in the final model		
Variable	***P* value**	**Variable**	**OR (95% CI)**	***P* value**
Age older than 65 y	.015	Age older than 65 y	2.16 (1.01-5.33)	.039
Male sex	.221			
Surgeon	.799			
Hypertension	.126			
Diabetes mellitus	.380			
Coronary artery disease	.467			
Chronic obstructive pulmonary disease	.753			
Chronic kidney disease	.753			
History of stroke	.787			
NYHA functional class III to IV	.810			
Left atrial diameter	.347			
Left ventricular end-systolic diameter	.492			
Left ventricular end-diastolic diameter	.336			
LVEF	.183			
Minimally invasive	.654			
Location of degenerative lesion	.312			
Cleft closure	.201			
Leaflet resection	.967			
Quadrangular resection	.657			
Sliding technique	.519			
Neochordal replacement	1.000			
Loop-in-loop technique	.519			
Edge-to-edge technique	.167			
Commissuroplasty	.900			
Leaflet plication	.467			
Full annuloplasty ring	.123			
Indexed prosthetic size	.095			
Tricuspid annuloplasty	.330			
Postoperative left atrial diameter	.278			
Postoperative left ventricular end-systolic diameter	.454			
Postoperative left ventricular end-diastolic diameter	.385			
Postoperative LVEF	.555			
Postoperative MR	.607			
PTMG >3 mm Hg	<.001	PTMG >3 mm Hg	3.93 (1.55-9.96)	.004
Early AF	<.001	Early AF	4.12 (1.94-8.93)	<.001
β-Blocker	.099			
ACEI/ARB	.388			

OR, Odds ratio; *CI*, confidence interval; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *MR*, mitral regurgitation; *PTMG*, postoperative transmitral gradient; *ACEI/ARB*, angiotensin converting enzyme inhibitor/angiotensin II receptor blocker.