Original Article

Patch augmentation *vs.* valve replacement for patients with atrial functional mitral regurgitation and long-standing atrial fibrillation

Akimasa Morisaki[1]^, Yosuke Takahashi[1], Hiromichi Fujii[1], Yoshito Sakon[1], Takashi Murakami[2], Toshihiko Shibata[1]

[1]Department of Cardiovascular Surgery, Osaka Metropolitan University Graduate School of Medicine, Osaka, Japan; [2]Department of Cardiovascular Surgery, Osaka City General Hospital, Osaka, Japan

Contributions: (I) Conception and design: A Morisaki, T Shibata; (II) Administrative support: None; (III) Provision of study materials or patients: A Morisaki, Y Takahashi, Y Sakon, T Murakami; (IV) Collection and assembly of data: A Morisaki, Y Takahashi, H Fujii, Y Sakon, T Murakami; (V) Data analysis and interpretation: A Morisaki, T Shibata; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Akimasa Morisaki, MD, PhD. Department of Cardiovascular Surgery, Osaka Metropolitan University Graduate School of Medicine, 1-4-3 Asahimachi, Abeno-ku, Osaka 545-8585, Japan. Email: m3_514@yahoo.co.jp.

Background: Long-standing atrial fibrillation is associated with atrial functional mitral regurgitation (AFMR) with atriogenic tethering. We compared the outcomes of patch augmentation (PA) and valve replacement (VR) for AFMR.

Methods: We retrospectively compared the data of 16 patients who underwent PA for AFMR with the data of 15 patients who underwent VR between 2008 and 2021. Patients with a left ventricular ejection fraction (LVEF) of <50% were excluded. We also performed atrial plication and left appendage closure if the patients had no weak atrial wall that led to severe bleeding.

Results: The median age was 72.5 and 76.0 years in the PA and VR groups, respectively. The PA group had a longer cardiopulmonary bypass time (206 *vs.* 172 min, P=0.012). Although there were no differences in hospital morbidity and mortality between the PA and VR groups, one patient underwent reoperation for patch perforation in the PA group. The overall 3-year survival rate was 93.8% and 100% in the PA and VR groups, respectively (P=0.878). The 3-year rate of freedom from major adverse cardiac events was 75.0% and 53.6% in the PA and VR groups, respectively (P=0.181). Three and six patients were readmitted for congestive heart failure in the PA and VR groups, respectively. Two patients in the PA group developed severe recurrent regurgitation, including one patient who required reoperation. No patients in the VR group required reoperation. The postoperative left atrial volume index (LAVI) was associated with thromboembolic events (P=0.016).

Conclusions: PA may achieve comparable outcomes to those of VR for AFMR. Operative procedures should be chosen based on each patient's background. Atrial reduction could be considered to prevent thromboembolic events.

Keywords: Atrial functional mitral regurgitation (AFMR); atrial fibrillation; atrial enlargement; patch augmentation (PA); valve replacement (VR)

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^ ORCID: 0000-0001-9736-5257.

Introduction

The mechanism of atrial functional mitral regurgitation (AFMR) and atrial fibrillation, including mitral annular dilatation and posterior leaflet tethering associated with left atrial enlargement, has gradually been elucidated (1). Recently, surgical interventions for AFMR due to atrial fibrillation have become an area of interest because different techniques are required at each stage of AFMR according to the pathology (2,3). Atrial fibrillation often causes mitral annular and left atrial dilatation, which lead to insufficient coaptation of the mitral leaflets. Some patients who have long-standing atrial fibrillation develop AFMR and posterior leaflet tethering due to deviation of the posterior leaflet. This deviation is caused by considerable dilation of the mitral annulus and the left atrium (atriogenic tethering or atrial hamstringing) (1). Sakaguchi *et al.* reported that ring annuloplasty for AFMR with excessive leaflet tethering may not be sufficient to achieve long-term correction of mitral regurgitation (MR) (2). Therefore, AFMR with long-standing atrial fibrillation, which is associated with severe shortening of the posterior leaflet with tethering, requires intervention for the shortened or tethered posterior leaflet. Ring repair alone cannot control AFMR because of insufficient leaflet coaptation, which is associated with recurrent MR.

Recently, PA repair for a shortened or tethered posterior leaflet in patients with AFMR and long-standing atrial fibrillation has been used (3,4). However, few studies have examined the outcomes of PA repair for AFMR (3,4), and the outcomes of PA repair have not been compared with those of mitral VR. Therefore, in this retrospective study, we compared the outcomes of PA repair with a tethered posterior leaflet with those of mitral VR for AFMR with long-standing atrial fibrillation. We present the following article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-828/rc).

Methods

Ethical statement

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Institutional Review Board of Osaka Metropolitan Medical School Hospital and Osaka City General Hospital (approval No. 3817; approval date, 31 July 2017). Written informed consent for this retrospective study was obtained from all the patients at the time of cardiovascular surgery.

Patients

From April 2008 to November 2021, we performed mitral valve repair with PA in 16 patients who had AFMR with a tethered posterior leaflet and severe left atrial enlargement due to long-standing atrial fibrillation at Osaka Metropolitan University Hospital and Osaka City General Hospital. Additionally, we performed mitral VR for AFMR with a tethered posterior leaflet and severe left atrial enlargement due to long-standing atrial fibrillation in 23 patients between April 2012 and November 2021 at Osaka Metropolitan University Hospital. The patients who had congestive heart failure caused by AFMR and long-standing atrial fibrillation even after medical management, including rhythm control, were eligible for inclusion in the study. We excluded patients with a reduced left ventricular (LV) ejection fraction (LVEF) (<50%) because decreased LV function may be associated with other cardiac diseases. Finally, we compared the outcomes of PA (n=16; PA group) with those of VR (n=15; VR group) for AFMR with a tethered posterior leaflet and severe atrial enlargement due to long-standing atrial fibrillation. We defined AFMR with a tethered posterior leaflet as severe shortening and tethering of the posterior leaflet and mitral annular dilatation with or without pseudo-prolapse of the anterior leaflets in accordance with the guidelines of the Japanese Circulation Society (5). Preoperative comorbidities and perioperative complications were defined by referring to the Japan Cardiovascular Surgery Database (http://www.jacvsd.umin.jp). Major adverse cardiac events after hospital discharge included cardiac death, readmission for congestive heart failure, cardiac thromboembolic events, and cardiac reoperation.

Surgical techniques

We performed mitral valve surgery for AFMR using the conventional approach, which consisted of cardiopulmonary bypass with ascending aortic cannulation and bicaval venous cannulation to the superior and inferior vena cava through a median sternotomy. We approached the mitral valve through the inferior approach or the transseptal approach. We performed aortic VR or coronary artery bypass grafting in the conventional fashion during cardiac arrest if necessary.

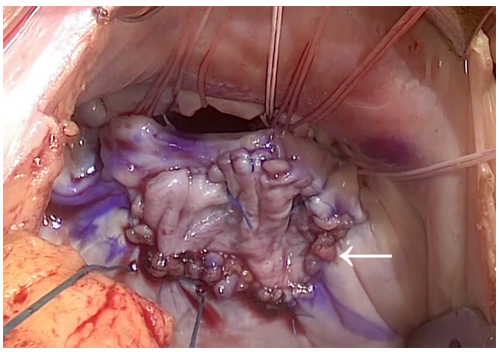

Figure 1 Image of intraoperative PA repair. The white arrow shows an autologous pericardial patch in the P2 posterior leaflet. PA, patch augmentation.

In the PA group, we performed PA with fresh autologous pericardium without glutaraldehyde fixation for AFMR to obtain an adequate coaptation length when the posterior leaflet was shorter than 10 mm (3,4). PA repair consisted of transversely cutting the center of the shortened posterior leaflet and sewing the pericardial patch using continuous suture with 5-0 monofilament polypropylene (*Figure 1*). The incision of the P2 posterior leaflet was extended to P1 or P3, where coaptation loss was identified using preoperative echocardiography or intraoperative findings. The harvested autologous pericardial patch was trimmed to a square shape to expand the height of the posterior leaflet over 20 mm during sewing. If the patients demonstrated pseudo-prolapse of the anterior leaflets, neochordal repair was performed with the loop technique using a CV4 expanded polytetrafluoroethylene suture (Gore-Tex®; W. L. Gore & Associates, Flagstaff, AZ, USA) and a felt pledget. The loop technique has been described previously (6). We selected a mitral ring that was one size smaller than the intercommissural distance.

In the VR group, we placed a bioprosthetic valve or mechanical valve with non-everting or everting mattress spaghetti-pledged 2-0 polyester suture. We removed the mitral valve leaflets and tendons without preserving subvalvular tissue because residual subvalvular tissue might have pannus formation, which may be associated with limiting prosthetic valve leaflet motion in the future.

Left atrial plication using horizontal mattress and continuous 4-0 Prolene suture with a felt pledget was performed from the left atrial appendage to the caudal atrial septum close to the posterior leaflet annulus, and from the left atrial appendage to the cranial atrial septum through the left atrial roof, with or without the middle posterior leaflet annulus to the left atrial roof through the posterior wall of the left atrium between the left and right pulmonary veins (Figure S1). Left atrial appendage was closed by intra-atrial horizontal mattress and continuous 4-0 Prolene suture without devices. Right atrial plication was also performed to plicate the right atriotomy with removal of the redundant right atrium. We did not perform atrial plication and left atrial appendage closure if the patients had a weak atrial wall that led to severe bleeding.

Anticoagulant therapy

After surgery, the patients underwent oral anticoagulant therapy with warfarin or non-vitamin K antagonist direct oral anticoagulants. Warfarin was controlled within 1.8–2.2 of the international normalized ratio as the standard, and within 2.0–2.5 of the international normalized ratio in patients who underwent mechanical VR. If the patients had a bleeding tendency, we controlled warfarin at a lower level of the international normalized ratio than the standard level.

Echocardiography

All patients underwent transthoracic echocardiography before and after surgery. The left atrial volume index (LAVI) was calculated by dividing the left atrial volume by the body surface area. MR severity was defined using a multiparametric approach, including assessments of the color Doppler-derived jet area, the effective regurgitant orifice area, the MR volume and fraction, and the pulmonary vein flow velocity pattern (7). The mean mitral valve pressure gradient (PG) was obtained by tracing the continuous wave Doppler signal for integration of instantaneous gradients over the diastolic filling period. The severity of tricuspid regurgitation (TR) was defined using a multiparametric approach, including assessments of the color Doppler-derived jet area, the continuous wave Doppler-derived jet density and contour, and the hepatic vein flow velocity pattern (7). Continuous wave Doppler was used to measure tricuspid valve peak velocity (v) (in m/s) and the TR PG (in mmHg), which was calculated as $4 \times v^2$. We measured the P2 posterior leaflet lengths and the posterior leaflet tethering angle in mid-systole. The posterior leaflet tethering angle was defined as the angle comprising the annular line, and the line drawn between the posterior annulus and the tip of the posterior leaflet (3).

The patients who had coaptation loss and a short length (<12 mm) of the posterior leaflet with a posterior leaflet tethering angle >30 degrees were candidates for this study.

Follow-up

Excluding the patients who died and underwent reoperation with VR for recurrent MR during hospitalization, 29 patients were followed up as outpatients every 6–12 months. Follow-up patients were censored on the last known date of echocardiography for recurrent MR and on the last known date that they visited the hospital. The median follow-up duration was 1.7 years [interquartile range (IQR), 1.2–3.9 years]. The median follow-up index was 0.93 [IQR, 0.56–0.98].

Statistical analysis

Data were analyzed using EZR, version 1.52 (Saitama Medical Center, Jichi Medical University, Saitama, Japan). Numerical variables are expressed as median [IQR] and were analyzed using the non-parametric Mann-Whitney U test. Categorical variables are expressed as number (percentage) and were compared using the χ^2 test or Fisher's exact test, as appropriate. The overall survival rate, rate of freedom from major adverse cardiac events after hospital discharge, rate of readmission for congestive heart failure, thromboembolic event rate, and cardiac reoperation rate were expressed using Kaplan-Meier estimates, and differences between the two groups were evaluated using the log-rank test. The univariate Cox regression analysis was used to identify the factors associated with thromboembolic events. Receiver operating characteristic (ROC) curves were designed to identify cut-off values to predict the risk of thromboembolic events. The specificity and sensitivity were calculated, as well as the positive and negative predictive values. The best possible cut-off point was defined as the highest Youden index [(specificity + sensitivity) – 1]. A P value of <0.05 was considered statistically significant.

Results

Patients' preoperative and intraoperative characteristics

Table 1 summarizes the preoperative and intraoperative characteristics in the PA and VR groups. The median age of patients was 72.5 [67.8–78.3] and 76.0 [74.5–80.0] years in the PA and VR groups, respectively (P=0.160). The VR group had a significantly higher rate of chronic renal disease than the PA group (P=0.009). There was no significant difference in LAVI. The median preoperative TR PG was 30.5 and 39.0 mmHg in the PA and VR groups, respectively (P=0.072). The PA group had a lower EuroScore II than the VR group (PA: 2.81 *vs.* VR: 4.82, P=0.027).

Fifteen patients in the PA group underwent mitral valve repair with the Carpentier-Edwards Physio II annuloplasty ring (Edwards Lifesciences, Irvine, CA, USA) (28 mm in two patients, 30 mm in five patients, 32 mm in five patients, 34 mm in two patients, 36 mm in one patient), while the SJM Rigid Saddle Ring (Abbott Laboratories, Chicago, IL, USA) was used in one patient (30 mm). Six patients concomitantly underwent the loop technique for anterior leaflet prolapse. Four patients in the VR group underwent VR with the Mosaic bioprosthesis (Medtronic Inc., Minneapolis, MN, USA), while the Epic valve (Abbott Laboratories) was used in eight patients, the Carpentier-Edwards PERIMOUNT valve (Edwards Lifesciences) was used in one patient, the SJM mechanical valve (Abbott Laboratories) was used in one patient, and the ATS mechanical valve (Medtronic) was used in one patient. All patients underwent concomitant tricuspid valve repair. Only one patient underwent the DeVega procedure for severe tricuspid valve regurgitation in the VR group, whereas 30 patients underwent ring annuloplasty. In the PA group, two patients underwent PA of the tricuspid valve anterior leaflet due to anterior leaflet shortening. Atrial plication was performed in 16 patients, and left atrial appendage closure was performed in 25 patients. The PA group had a longer operation time (PA: 345 *vs.* VR: 288 min, P=0.086), cardiopulmonary bypass time (PA: 206 *vs.* VR: 172 min, P=0.012), and aortic clamp time (164 *vs.* 137 min, P=0.058) than the VR group.

Postoperative outcomes during hospitalization

Table 2 shows the postoperative outcomes of patients during hospitalization. After surgery, one patient in the PA group who did not undergo atrial plication and left appendage closure died of cerebral infarction caused by cardiac thrombosis, whereas no patients died in the VR group (P=1.000). Six patients in each group had postoperative morbidities (P=1.000). One patient required mitral VR for perforation of the patched posterior leaflet (Figure S2). Five patients required re-exploration for bleeding (PA: 2 patients *vs.* VR: 3 patients). Postoperative LAVI, mean mitral valve PG, and TR PG were not significantly

Table 1 Patients' perioperative and intraoperative characteristics

Variables	PA group (n=16)	VR group (n=15)	P value
Age, years	72.5 [67.8–78.3]	76.0 [74.5–80.0]	0.160
Sex, female/male	4 (25.0)/12 (75.0)	7 (46.7)/8 (53.3)	0.273
BSA, m^2	1.67 [1.57–1.73]	1.51 [1.41–1.69]	0.206
Hypertension	9 (56.3)	12 (80.0)	0.252
Dyslipidemia	2 (12.5)	2 (13.3)	1.000
Diabetes mellitus	1 (6.3)	1 (6.7)	1.000
Smoking	8 (50.0)	6 (40.0)	0.722
Chronic renal disease	2 (12.5)	9 (60.0)	0.009
Hemodialysis	0 (0.0)	1 (6.7)	1.000
Cerebrovascular disease	0 (0.0)	4 (26.7)	0.043
Respiratory disease	2 (12.5)	3 (20.0)	0.654
Previous cardiac surgery	1 (6.3)	2 (13.3)	0.600
NYHA class ≥III	9 (56.3)	10 (66.7)	0.716
Preoperative LVEF, %	60.0 [59.0–67.5]	63.0 [58.5–66.0]	0.984
Preoperative LV diastolic dimension, mm	59.5 [53.8–61.5]	54.0 [51.3–56.0]	0.205
Preoperative LAVI, mL/m^2	131.4 [77.0–202.6]	161.0 [85.5–202.5]	0.711
Preoperative MR grade			1.000
Moderate to severe	2 (12.5)	1 (6.7)	
Severe	14 (87.5)	14 (93.3)	
Preoperative TR PG, mmHg	30.5 [28.0–38.0]	39.0 [31.1–52.5]	0.072
Preoperative TR grade			0.639
Mild	2 (12.5)	1 (6.7)	
Moderate	8 (50.0)	6 (40.0)	
Moderate to severe	0 (0.0)	2 (13.3)	
Severe	6 (37.5)	6 (40.0)	
EuroScore II	2.81 [2.33–5.31]	4.82 [3.13–9.20]	0.027
Operation time, min	345 [309–404]	288 [264–344]	0.086
Cardiopulmonary bypass time, min	206 [183–236]	172 [153–192]	0.012
Aortic clamp time, min	164 [149–178]	137 [126–161]	0.058
Concomitant operation			
Aortic VR	0 (0.0)	1 (6.7)	0.484
Coronary artery bypass grafting	0 (0.0)	2 (13.3)	0.226
Atrial plication	7 (43.8)	9 (60.0)	0.479
Left atrial appendage closure	11 (68.8)	14 (93.3)	0.172

Data are presented as n (%) or median [interquartile range]. PA, patch augmentation; VR, valve replacement; BSA, body surface area; NYHA, New York Heart Association; LVEF, left ventricular ejection fraction; LV, left ventricular; LAVI, left atrial volume index; MR, mitral regurgitation; TR, tricuspid regurgitation; PG, pressure gradient.

Table 2 Postoperative data during hospitalization

Variables	PA group (n=16)	VR group (n=15)	P value
Postoperative LVEF, %	57.5 [53.0–62.3]	55.0 [49.5–59.0]	0.177
Postoperative LV diastolic dimension, mm	52.0 [47.0–55.3]	45.0 [43.5–54.0]	0.227
Postoperative LAVI, mL/m^2	86.8 [58.9–118.3]	67.0 [45.0–92.0]	0.173
Postoperative mean mitral valve PG, mmHg	4.0 [3.0–5.0]	4.0 [4.0–7.0]	0.144
Postoperative MR grade			0.673
None or trivial	12 (75.0)	14 (93.3)	
Mild	3 (18.8)	1 (6.7)	
Mild to moderate	1 (6.3)	0 (0.0)	
Postoperative TR PG, mmHg	25.0 [22.0–27.0]	25.2 [24.0–40.0]	0.355
Postoperative TR grade			0.722
Trivial	10 (62.5)	7 (46.7)	
Mild	5 (31.3)	7 (46.7)	
Moderate	1 (6.3)	1 (6.7)	
Mortality	1 (6.3)	0 (0.0)	1.000
Morbidities	6 (37.5)	6 (40.0)	1.000
Reoperation for recurrent MR	1 (6.3)	0 (0.0)	
Re-exploration for bleeding	2 (12.5)	3 (20.0)	
Cerebral infarction	1 (6.3)	0 (0.0)	
Low output syndrome	1 (6.3)	0 (0.0)	
LV rupture	0 (0.0)	1 (6.7)	
Need for continuous hemodialysis	2 (12.5)	1 (6.7)	
Pneumonia	1 (6.3)	2 (13.3)	
Tracheotomy	0 (0.0)	2 (13.3)	
Pacemaker implantation	0 (0.0)	2 (13.3)	

Data are presented as n (%) or median [interquartile range]. PA, patch augmentation; VR, valve replacement; LVEF, left ventricular ejection fraction; LV, left ventricular; LAVI, left atrial volume index; PG, pressure gradient; MR, mitral regurgitation; TR, tricuspid regurgitation.

different between the PA and VR groups. In the PA group, postoperative MR grade was less than mild in fifteen patients, and mild to moderate in one patient. The postoperative TR grade was not significantly different between the PA and VR groups.

Mid-term outcomes: *survival rate and major adverse cardiovascular event rate*

The overall survival rate was 93.8% and 100% at 3 years and 75.0% and 50.0% at 5 years in the PA and VR groups, respectively (P=0.878) (*Figure 2*, Table S1). The cause of late death was cancer in two patients in the PA group and congestive heart failure in one patient in the VR group. The rate of freedom from major adverse cardiac events after hospital discharge was 75.0% and 53.6% at 3 years and 56.2% and 26.8% at 5 years in the PA and VR groups, respectively (P=0.181) (*Figure 3A*, Table S1). In the PA group, two patients had recurrent severe MR, and two patients required reoperation owing to recurrent MR and left atrial thrombosis. Two patient who did not undergo atrial plication and left appendage had cerebral infarction and

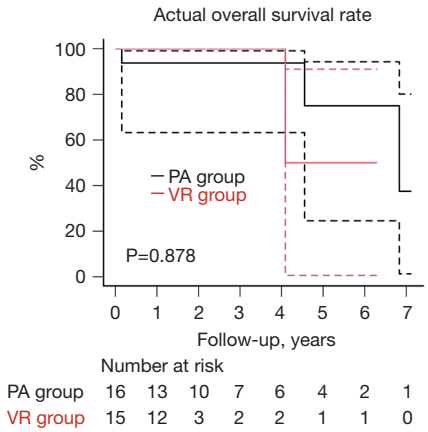

Figure 2 Overall survival rate of patients who underwent PA and VR for AFMR analyzed by the Kaplan-Meier method. PA, patch augmentation; VR, valve replacement; AFMR, atrial functional mitral regurgitation.

left atrial thrombosis. Three patients were readmitted to hospital owing to congestive heart failure. In the VR group, six patients were readmitted to hospital owing to congestive heart failure associated with chronic atrial fibrillation, including one patient with a permanent pacemaker for sick sinus syndrome. One patient who underwent mechanical VR experienced cerebral bleeding. No patients in the VR group required reoperation or demonstrated structural valve deterioration. The rate of freedom from readmission for congestive heart failure, thromboembolic events, and cardiac reoperation after hospital discharge have no significant difference, respectively (P=0.093, 0.272, and 0.269) (*Figure 3B-3D*, Table S1).

Factors associated with thromboembolic events

We assessed the factors associated with thromboembolic events over the entire period. The univariate Cox regression analysis showed that postoperative LAVI (hazard ratio 1.02; 95% CI: 1.004–1.034; P=0.016) was associated with thromboembolic events (*Table 3*). The ROC curve showed that the postoperative LAVI cut-off value for thromboembolic events was 106.9 mL/m^2 (specificity, 0.857; sensitivity, 1.000; area under the curve, 0.917; 95% CI: 0.801–1.000) (*Figure 4*).

Discussion

Long-standing atrial fibrillation is associated with significant functional MR and TR, which is in turn associated with a very poor prognosis despite preserved LVEF (8). In this situation, surgical interventions are recommended to improve prognosis (3,9). Mitral valve repair with ring annuloplasty only for AFMR with excessive posterior leaflet shortening and tethering does not effectively control MR (2). Additional repair techniques, such as PA repair, are required to obtain good mitral valve leaflet coaptation. Mitral VR may be useful because patients with long-standing atrial fibrillation are usually older with severe degenerative changes in the mitral leaflets. However, few studies have reported the outcomes of PA repair compared with those of mitral VR for AFMR with a tethered posterior leaflet. Our study showed that PA repair for AFMR with a tethered posterior leaflet and severe atrial enlargement achieves comparable outcomes to those of mitral VR.

PA repair provides good mitral valve leaflet coaptation, which leads to good control of MR. Recent studies have shown good early outcomes with low rates of recurrent MR and reoperation after PA for ischemic MR or rheumatic disease by deep leaflet coaptation (10,11). Additionally, Rahmani *et al.* revealed that posterior leaflet PA significantly reduces the forces on the chordae tendinae from the posterior papillary muscle with good hemodynamics *in vitro* using a functional ischemic MR valve simulation (12). However, PA repair had relatively higher recurrent MR and reoperation rates than the other mitral valve repair techniques. Fukunaga *et al.* reported a lower freedom from reoperation rate after PA than with non-PA repair (93.4% *vs.* 96.9% and 68.8% *vs.* 89.7% at 2 and 5 years, respectively) (13). Additionally, PA repair carries a risk of patch detachment or rupture after surgery, as well as calcification of glutaraldehyde-fixed pericardium (13,14). We also experienced three patients with recurrent MR, including one patient with patch perforation and two patients who required reoperation in the relatively early-term. No patients demonstrated calcification of the pericardial patch, which may be because we did not use glutaraldehyde-fixed pericardium. A recent report showed that in mitral valve repair, fresh autologous pericardium can be used with the expectation of durable long-term valve function without evidence of late patch calcification, stiffness, or aneurysmal degeneration (15). In contrast, Ikeda *et al.* reported that extended PA was not associated with recurrent MR or reoperation 3 years after surgery, which emphasizes the importance of large and wide augmentation to prevent recurrent MR (11). In the present study, PA

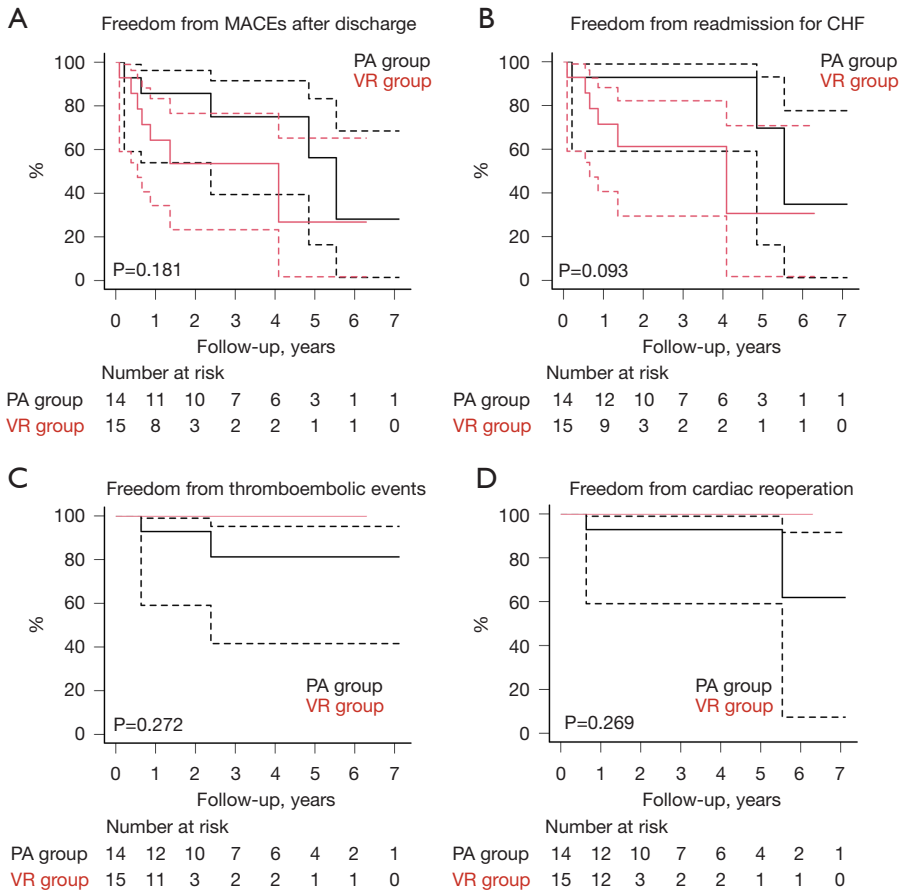

Figure 3 Freedom from MACEs (A), readmission for CHF (B), thromboembolic events (C), and cardiac reoperation (D) after hospital discharge in patients who underwent PA *vs.* VR for AFMR analyzed using the Kaplan-Meier method. MACEs, major adverse cardiac events; PA, patch augmentation; VR, valve replacement; CHF, congestive heart failure; AFMR, atrial functional mitral regurgitation.

repair required longer cardiopulmonary bypass and cardiac arrest times than mitral VR, even though the patients who underwent VR usually underwent concomitant procedures. A recent meta-analysis showed a good long-term outcome with a low reoperation rate after mitral bioprosthetic VR for MR (16). In high-risk patients, VR may be a useful procedure to obtain good outcomes with a low reoperation rate. PA or VR should be chosen based on the patient's background.

Long-standing atrial fibrillation is also associated with severe right and left atrial enlargement, usually with MR and TR, which requires additional atrial reduction surgery (17). Severe atrial enlargement leads to smoke-like flow in the atrium with a possibility of thrombosis and compression of the bronchus and lung, followed by decreased respiratory function (18). Therefore, atrial reduction surgery is required to improve atrial function and lung compression. Sawazaki *et al.* showed that aggressive atrial volume reduction of bilateral enlarged atria improved respiratory function (19). Moreover, recent studies have shown that left atrial volume reduction concomitant with atrial fibrillation surgery helped to restore both left atrial contraction and compliance with a high rate of restoration to sinus rhythm (20,21). Matsumori *et al.* also suggested that left atrial plication improved the horizontal mitral valve angle, which affected the durability of mitral valve repair (22). Additionally, our results show that LAVI is associated with thromboembolic events after surgery for AFMR, and the patients who did not undergo atrial plication and left atrial appendage closure had thromboembolic events. Therefore, atrial reduction surgery with appropriate volume reduction is needed to prevent or improve the events associated with atrial enlargement. However, atrial reduction surgery poses a risk of bleeding because of inherent weakening of the atrial wall, although

Table 3 Univariate Cox regression analysis of factors for thromboembolic events over the entire period

Variables	Thromboembolic events		
	Hazard ratio	95% CI	P value
Age, years	0.95	0.820–1.100	0.490
Sex, male	0.99	0.089–10.96	0.993
Hypertension	<0.01	0–inf	0.999
Chronic renal disease	<0.01	0–inf	0.999
Cerebral disease	<0.01	0–inf	0.999
NYHA ≥3	1.19	0.105–13.48	0.888
Preoperative LV diastolic dimension, mm	0.97	0.849–1.116	0.702
Preoperative TR PG, mmHg	0.97	0.864–1.093	0.636
VR	<0.01	0–inf	0.999
Atrial plication	<0.01	0–inf	0.999
Left atrial appendage closure	<0.01	0–inf	0.999
Postoperative LAVI, mL/m^2	1.02	1.004–1.034	0.016
Postoperative TR PG, mmHg	1.04	0.915–1.175	0.570

For numerical variables, the hazard ratio refers to an increase of 1. CI, confidence interval; inf, infinity; NYHA, New York Heart Association; LV, left ventricular; TR, tricuspid regurgitation; PG, pressure gradient; VR, valve replacement; LAVI, left atrial volume index.

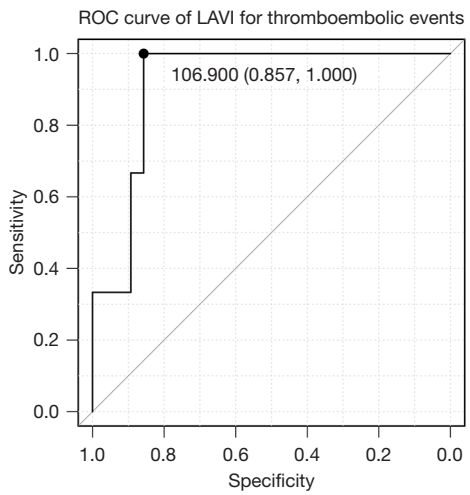

Figure 4 ROC curve of LAVI for thromboembolic events. The LAVI cut-off value for thromboembolic events was 106.9 mL/m^2 (specificity, 0.857; sensitivity, 1.000; AUC, 0.917; 95% CI: 0.801–1.000). ROC, receiver operating characteristic; LAVI, left atrial volume index; AUC, area under the curve; CI, confidence interval.

several atrial reduction techniques, including plication and resection, have been reported with good outcomes (18). Thus, the technique should be chosen with consideration of the bleeding risk.

The mortality and morbidity rates of surgery for atrial enlargement are high. Long-standing atrial fibrillation is associated with huge atrial enlargement with MR and TR, followed by left and right congestive heart failure (8). Zheng *et al.* reported an operative mortality rate of 13%, a low cardiac output syndrome rate of 13%, and a respiratory failure rate of 10% after surgery for left atrial enlargement (23). Our results also showed that 6.5% of patients experienced respiratory complications requiring tracheotomy. In particular, the VR group had a high tracheotomy rate, which may have been derived from the higher EuroScore II compared with the PA group. Furthermore, patients who had long-standing atrial fibrillation with atrial enlargement were usually older and had chronic heart failure, which is associated with weak tissues and cardiac cachexia (24). Our results also showed a relatively high morbidity rate, including reoperation for postoperative bleeding and LV rupture, although few patients with low output syndrome required intra-aortic balloon pumping. Coagulopathy caused by heart failure and weak tissue injury may lead to a bleeding tendency and LV rupture. Additionally, some patients had congestive heart failure or required pacemaker implantation after surgery.

Long-standing atrial fibrillation that cannot be corrected carries a risk of sinus node dysfunction and persistent pulmonary hypertension, which induces congestive heart failure and requires permanent pacemaker implantation (8,25). Therefore, because patients with long-standing atrial fibrillation may develop congestive heart failure even after surgery, medical treatments should be carefully considered in cooperation with a cardiologist.

This study has some inherent limitations that should be noted. First, the study was retrospective in nature and was not a randomized controlled study. Moreover, inherited risk factors that we could not detect or exclude may have led to selection bias. Heterogeneity of repair for AFMR and concomitant operations may also affect the outcomes. In addition, the PA group had a lower EuroScore II and a higher rate of renal and cerebral diseases than the VR group, which may have affected the outcomes. Second, the number of included patients was relatively small, which may have influenced the results. However, it may be difficult to obtain a large number of patients with AFMR and to exclude selection bias because the number of patients with AFMR is relatively small (1,8). Finally, the follow-up duration may have been too short to declare robust long-term results after surgery for AFMR. Therefore, further follow-up is required to examine the outcomes after surgery for AFMR.

Conclusions

PA repair for AFMR caused by severe posterior leaflet shortening with atrial enlargement may achieve good outcomes that are comparable with those of VR. However, PA repair required a longer cardiopulmonary bypass time and had a higher reoperation rate than VR. Therefore, in high-risk patients, VR may be a good choice because of its good mid-term outcomes without reoperation, especially for non-expert surgeons. Surgical procedures should be chosen while considering the patient's background. Atrial reduction surgery with appropriate volume reduction could be considered to prevent thromboembolic events because the postoperative LAVI is associated with thromboembolic events after surgery.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-828/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Institutional Review Board of Osaka Metropolitan Medical School Hospital and Osaka City General Hospital (approval No. 3817), and written informed consent was obtained from all the patients.

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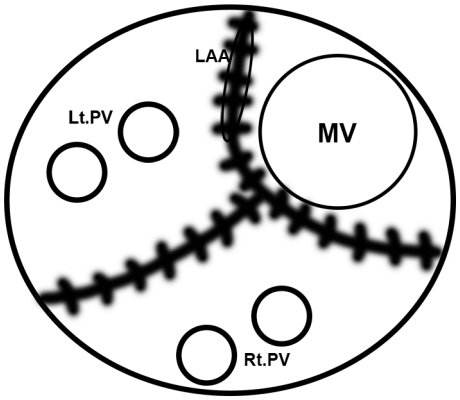

Figure S1 Intraoperative schema of atrial plication. LAA, left atrial appendage; MV, mitral valve; Rt., right; PV, pulmonary vein; Lt., left.

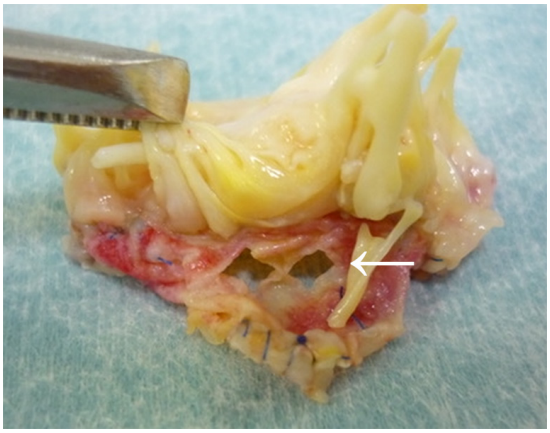

Figure S2 Intraoperative image of patch perforation in the posterior leaflet. The image is the view from the LV side. The white arrow indicates perforation on the pericardial patch, not on the sewn portion. LV, left ventricular.

Table S1 Overall survival rate of patients and freedom from MACEs after hospital discharge in patients who underwent PA *vs.* VR for AFMR analyzed using the Kaplan-Meier method

	Rate at 1 year (95% CI)	Rate at 3 years (95% CI)	Rate at 5 years (95% CI)	P value
Overall survival rate				
PA group	93.8% (0.632–0.991)	93.8% (0.632–0.991)	75.0% (0.245–0.943)	0.878
VR group	100%	100%	50.0% (0.006–0.910)	
Freedom from MACEs after hospital discharge				
PA group	85.7% (0.539–0.962)	75.0% (0.394–0.915)	56.2% (0.164–0.833)	0.181
VR group	64.3% (0.343–0.833)	53.6% (0.233–0.766)	26.8% (0.017–0.652)	
Freedom form readmission for CHF after hospital discharge				
PA group	92.9% (0.591–0.990)	92.9% (0.591–0.990)	69.6% (0.162–0.931)	0.093
VR group	71.4% (0.406–0.882)	61.2% (0.294–0.821)	30.6% (0.017–0.708)	
Freedom from thromboembolic events after hospital discharge				
PA group	92.9% (0.591–0.990)	81.2% (0.415–0.952)	81.2% (0.415–0.952)	0.272
VR group	100%	100%	100%	
Freedom from cardiac reoperation after hospital discharge				
PA group	92.9% (0.591–0.990)	92.9% (0.591–0.990)	92.9% (0.591–0.990)	0.269
VR group	100%	100%	100%	

MACEs, major adverse cardiac events; PA, patch augmentation; VR, valve replacement; AFMR, atrial functional mitral regurgitation; CI, confidence interval; CHF, congestive heart failure.

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