

# Papillary Muscle Repositioning as a Subvalvular Apparatus Preservation Technique

in Mitral Stenosis Patients with  
Normal Left Ventricular Systolic Function

**Gokhan Lafci, MD**  
**Kerim Cagli, MD**  
**Omer Faruk Cicek, MD**  
**Kemal Korkmaz, MD**  
**Osman Turak, MD**  
**Alper Uzun, MD**  
**Adnan Yalcinkaya, MD**  
**Adem Diken, MD**  
**Eren Gunertem, MD**  
**Kumral Cagli, MD**

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**From:** Departments of Cardiovascular Surgery (Drs. Kerim Cagli, Cicek, Diken, Gunertem, Lafci, and Yalcinkaya) and Cardiology (Drs. Kumral Cagli and Turak), Turkiye Yuksek Ihtisas Hospital, 06100 Ankara; Department of Cardiovascular Surgery (Dr. Korkmaz), Ankara Numune Education and Research Hospital, 06330 Ankara; and Department of Cardiovascular Surgery (Dr. Uzun), Ankara Education and Research Hospital, 06340 Ankara; Turkey

**Address for reprints:** Omer Faruk Cicek, MD, Department of Cardiovascular Surgery, Turkiye Yuksek Ihtisas Hospital, Kizilay Sok, 06100 Sıhhiye, Ankara, Turkey

**E-mail:** farux@hotmail.com

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*Subvalvular apparatus preservation is an important concept in mitral valve replacement (MVR) surgery that is performed to remedy mitral regurgitation. In this study, we sought to determine the effects of papillary muscle repositioning (PMR) on clinical outcomes and echocardiographic left ventricular function in rheumatic mitral stenosis patients who had normal left ventricular systolic function.*

*We prospectively assigned 115 patients who were scheduled for MVR surgery with mechanical prosthesis to either PMR or MVR-only groups. Functional class and echocardiographic variables were evaluated at baseline and at early and late postoperative follow-up examinations. All values were compared between the 2 groups.*

*The PMR group consisted of 48 patients and the MVR-only group of 67 patients. The 2 groups' baseline characteristics and surgery-related factors (including perioperative mortality) were similar. During the 18-month follow-up, all echocardiographic variables showed a consistent improvement in the PMR group; the mean left ventricular ejection fraction deteriorated significantly in the MVR-only group. Comparison during follow-up of the magnitude of longitudinal changes revealed that decreases in left ventricular end-diastolic and end-systolic diameters and in left ventricular sphericity indices, and increases in left ventricular ejection fractions, were significantly higher in the PMR group than in the MVR-only group.*

*This study suggests that, in patients with rheumatic mitral stenosis and preserved left ventricular systolic function, the addition of papillary muscle repositioning to valve replacement with a mechanical prosthesis improves left ventricular dimensions, ejection fraction, and sphericity index at the 18-month follow-up with no substantial undesirable effect on the surgery-related factors. (Tex Heart Inst J 2014;41(1):33-9)*

**M**itral valve replacement (MVR) with a mechanical or a bioprosthetic valve is one of the most performed cardiac surgical procedures. Although in recent years valve repair has usually been preferred to replacement, MVR is inevitable when repair is not feasible. After MVR, low cardiac output syndrome develops in some patients, because the subvalvular apparatus has not been spared.<sup>1</sup> Because the subvalvular apparatus provides continuity between the mitral annulus and the left ventricular (LV) wall through the leaflets, chordae tendineae, and papillary muscles, it plays an important role in LV function.<sup>2</sup> Several studies<sup>3-5</sup> have shown that protection of the subvalvular apparatus during MVR can decrease the risk of low cardiac output syndrome, reduce the operative mortality rate, and improve postoperative LV systolic function. Various approaches to subvalvular apparatus preservation have been developed.<sup>6-9</sup>

Papillary muscle repositioning (PMR) is a subvalvular apparatus-sparing method that can be applied to both the anterior and posterior mitral annulus. In patients with LV dysfunction and mitral regurgitation, several studies<sup>10,11</sup> have shown favorable effects of papillary muscle repositioning on LV remodeling; however, the effect of subvalvular-apparatus-sparing surgery (including PMR) on LV mechanics has not yet been fully elucidated in patients who have isolated mitral stenosis and preserved LV function.<sup>12,13</sup>

In this study, we examined the effectiveness of PMR on LV function and clinical outcome in patients with isolated mitral stenosis and preserved LV systolic function who undergo MVR.

## Patients and Methods

We prospectively assigned 115 patients who were scheduled for MVR after presenting with isolated rheumatic mitral stenosis and preserved LV systolic function—and who were not eligible for percutaneous treatment—into either PMR or MVR-only groups. Allocation of patients to either group was left to the surgeon's discretion, upon intraoperative evaluation of the valve. Patients whose papillary muscles were excessively retracted, or severely adherent to the adjacent myocardium, were allocated to the MVR-only group. Ultimately, 48 patients (13 men; mean age,  $49 \pm 11.9$  yr) underwent PMR as a subvalvular apparatus-sparing procedure, and 67 patients (18 men; mean age,  $52.5 \pm 14.8$  yr) underwent conventional MVR.

Table I shows a comparison of the 2 groups' baseline clinical characteristics and preoperative echocardiographic findings. There was no significant difference between the groups in terms of age, sex, preoperative New York Heart Association (NYHA) functional class, or echocardiographic findings, including LV end-diastolic (LVEDD) and end-systolic dimensions (LVESD), left ventricular ejection fraction (LVEF), LV sphericity index (LVSI), and systolic pulmonary artery pressures (SPAP).

Excluded from the study were patients with mitral valves suitable for posterior leaflet preservation, mitral

regurgitation of  $\geq 2$  degrees, LVEF of  $< 0.50$ , evidence of coronary artery disease, or additional surgical procedures to be performed concomitantly. Informed consent was obtained from all patients, and the study protocol was approved by our institutional ethical committee.

*Surgical Technique.* In MVR procedures, posterior leaflet preservation is the method of choice in our clinic. However, this study included MVR patients whose posterior leaflets could not be preserved because of anatomic reasons, such as massive fibrosis or calcification.

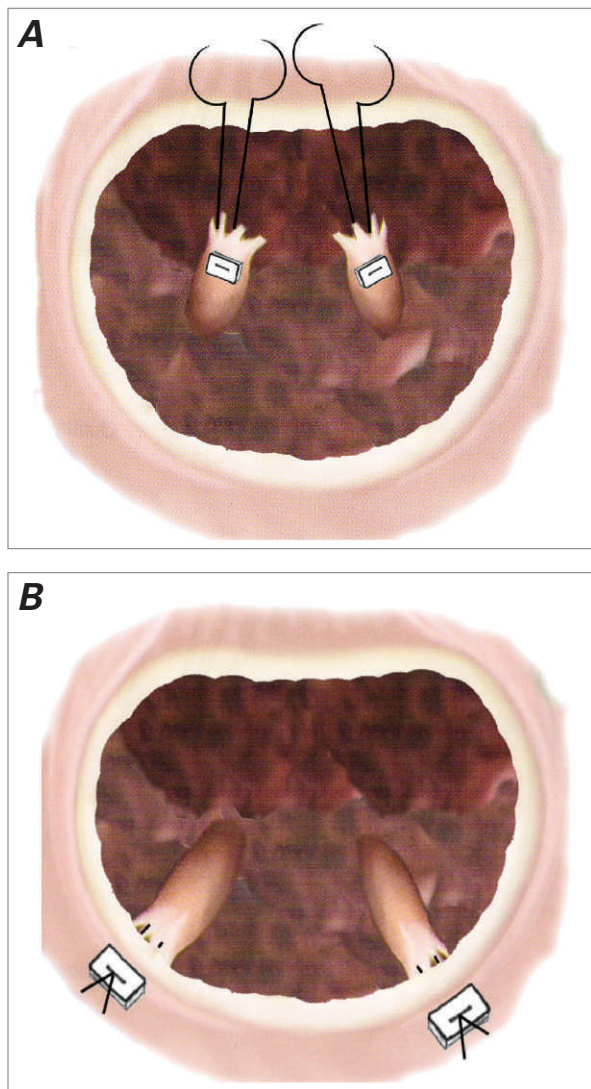
All 115 patients in the study underwent mitral valve surgery via a standard median sternotomy, with the use of cardiopulmonary bypass, mild systemic hypothermia ( $33^\circ\text{C}$ ), and cardioplegia via the administration of warm blood. The mitral valve was exposed through an interatrial incision; both leaflets and all chordal structures were entirely resected in all patients. In the MVR-only group, a mechanical mitral prosthesis, from 27 to 33 mm in size (St. Jude Medical, Inc.; St. Paul, Minn), was implanted by means of single pledgeted sutures. In the PMR group, a 2-0 double-needle pledgeted Ethibond suture (Ethicon Inc., a Johnson & Johnson company; Somerville, NJ) was placed through the heads of both papillary muscles from the posterior face to the anterior face (in a U-shaped pattern) and sutured to the posterior side of the annulus at approximately a 5- to 8-o'clock position, leaving no space between the heads of the papillary muscles and the annulus (Figs. 1 and 2). Then, a St. Jude mechanical prosthetic valve (27–33 mm in diameter) was implanted via single pledgeted sutures. At the end of the replacement procedure, valve motion (particularly in terms of restriction or impingement) was evaluated in all patients.

**TABLE I.** Baseline Preoperative Characteristics of the Patients

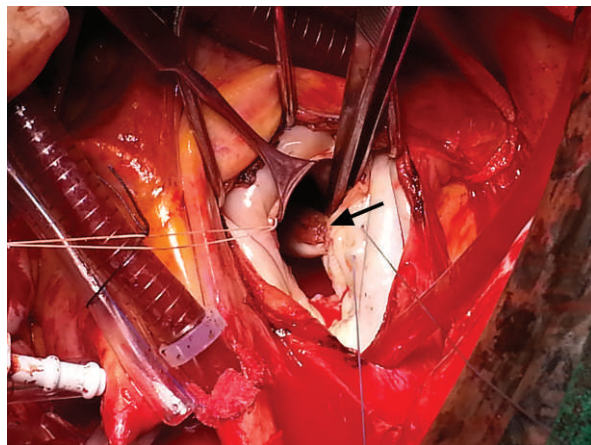
Variable	PMR Group (n=48)	MVR-Only Group (n=67)	P Value
Age, yr	49.04 $\pm$ 11.94	52.51 $\pm$ 14.81	0.186
Sex			0.98
Male	13 (27.1)	18 (26.9)	
Female	35 (72.9)	49 (73.1)	
NYHA functional class			0.96
II	7 (14.6)	10 (14.9)	
III	41 (85.4)	57 (85.1)	
LVEDD, cm	4.92 $\pm$ 0.74	4.67 $\pm$ 0.74	0.07
LVESD, cm	3.31 $\pm$ 0.7	3.11 $\pm$ 0.71	0.13
LVEF	0.54 $\pm$ 0.09	0.57 $\pm$ 0.09	0.23
LVSI	0.53 $\pm$ 0.03	0.54 $\pm$ 0.03	0.35
SPAP, mmHg	56.73 $\pm$ 15.57	56.51 $\pm$ 11.53	0.93

LVEDD = left ventricular end-diastolic dimension; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic dimension; LVSI = left ventricular sphericity index; MVR = mitral valve replacement; NYHA = New York Heart Association; PMR = papillary muscle repositioning; SPAP = systolic pulmonary artery pressure

Data are presented as mean  $\pm$  SD or as number and percentage.  $P < 0.05$  was considered statistically significant.



**Fig. 1** Schematic views show the **A)** first and **B)** 2nd steps of the papillary muscle repositioning.



**Fig. 2** Intraoperative photograph shows the mitral annulus and subvalvular apparatus after the posteromedial papillary muscle has been repositioned (arrow).

**Echocardiographic Evaluation.** Comprehensive transthoracic echocardiography with use of a Vivid 7® cardiac ultrasonographic system (GE VingMed Ultrasound AS; Horten, Norway) was performed in all study patients one week before surgery (preoperative period), before discharge from the hospital (early postoperative period), and at 18 months after surgery (late postoperative period). Mean values for each measurement were obtained from 3 consecutive heartbeats in sinus rhythm or from 5 consecutive beats in atrial fibrillation. The LVEF was measured by the method that uses Simpson's rule. The LVSI was calculated at end-diastole by dividing the maximal short-axis internal dimension by the LV maximal long-axis internal dimension. All echocardiographic data were obtained in accordance with the criteria of the American Society of Echocardiography. All echocardiographic evaluations were performed by the same experienced cardiologist, who was blinded to the patient's group. Correlation between the test and retest for LVEF and LVSI in preoperative, early postoperative, and late postoperative measurements was calculated by intraclass correlation coefficient (ICC) with 95% confidence intervals (95% CI). Agreement was found to be substantial for evaluation of LVEF (ICC=0.93) and LVSI (ICC=0.89) at preoperative evaluation. Early and late postoperative measurements for LVEF (ICC=0.88 and 0.91, respectively) and LVSI (ICC=0.90 and 0.93, respectively) also had high rates of agreement.

### Statistical Analysis

Statistical analysis was performed by using SPSS 15.0 statistical software (IBM Corporation; Armonk, NY). To test distribution patterns, the Kolmogorov-Smirnov test was used. All variables were found to be normally distributed, and these variables were given as mean  $\pm$  SD. Comparisons between groups were made using  $\chi^2$  tests for categorical variables, and results were given as percentages. The independent-samples Student's *t* test was used for normally distributed continuous variables. To test the significance of the longitudinal changes in each group regarding NYHA functional class and echocardiographic variables, repeated-measures analysis of variance was used. Differences between levels of each echocardiographic variable at the 18-month follow-up and at baseline were calculated in each group. These differences between the 2 groups were compared by using the independent-samples Student *t* test. A *P* value <0.05 was considered statistically significant.

### Results

Table II compares the 2 groups in regard to surgery-related factors. One patient in the MVR-only group died in the operating room because of pump failure; before discharge from the hospital, 1 patient in the PMR group and 2 patients in the MVR-only group died of respira-

**TABLE II.** Comparison of the Surgery-Related Factors between the 2 Groups

Variable	PMR Group (n=48)	MVR-Only Group (n=67)	P Value
Cross-clamp time, min	71.92 ± 13.4	65.55 ± 11.25	0.19
Cardiopulmonary bypass time, min	95.23 ± 12.8	87.48 ± 13.06	0.74
Intensive care unit stay, d	1.4 ± 0.69	1.16 ± 0.77	0.25
Postoperative need for positive inotropic agents	4 (8.3)	7 (10.4)	0.7
Postoperative complications			
Pleural effusion	4 (8.3)	7 (10.4)	0.7
Bleeding or tamponade	5 (10.4)	6 (9)	0.79
Arrhythmia	3 (6.3)	4 (6)	0.95
In-hospital death	1 (2.1)	3 (4.4)	0.49

MVR = mitral valve replacement; PMR = papillary muscle repositioning

Data are presented as mean ± SD or as number and percentage. *P* < 0.05 was considered statistically significant.

tory failure complicated by sepsis. There were no more deaths during the 18-month follow-up period.

Table III shows longitudinal changes in functional capacity and in echocardiographic values for the PMR group, and Table IV shows those changes for the MVR-only group. No patient was lost to follow-up in either group. In the PMR group (Table III), functional capacity improved significantly from baseline to 18-month follow-up: in particular, LVEDD and LVESD decreased and LVEF increased significantly. Left ventricular sphericity index and SPAP also showed significant improvement in the PMR group. In the MVR-only group (Table IV), functional capacity also improved from baseline to 18-month follow-up, but LVEDD did not change significantly and LVESD decreased—only to increase significantly during late follow-up. Left ventricular ejection fraction showed a consistent deterioration in the MVR-only group, but LVSI and SPAP improved significantly from baseline to the late postoperative follow-up (Table IV).

Table V compares the magnitude of the 2 groups' longitudinal changes during follow-up. This comparison revealed that the decrease in SPAP was similar in the PMR and MVR-only groups, but that the decreases in LVEDD, LVESD, and LVSI—and the increase in LVEF—are significantly higher in the PMR group.

## Discussion

This study suggests that, in patients with rheumatic mitral stenosis and preserved LV systolic function, the addition of papillary muscle repositioning to the replacement of the valve with a mechanical prosthesis improves the LV dimensions, ejection fraction, and sphericity index at 18-month follow-up, with no significant undesirable effect on the surgery-related factors.

In 1964, Lillehei and colleagues<sup>3</sup> showed for the first time that preservation of the posterior mitral leaflet

chordae can significantly decrease the mortality rate of MVR surgery. After that, several investigators examined the effects of various subvalvular-apparatus preservation techniques on early and late outcomes; however, most of those studies examined a small number of mitral stenosis patients or focused on mitral regurgitation patients to the exclusion of any other. In 1996, Straub and colleagues<sup>14</sup> studied a series of 82 patients who had a mean LVEF of approximately 0.40 and underwent MVR either with or without subvalvular apparatus-sparing. They concluded that chordal preservation improves LV function and geometry. In the Straub study, most patients had combined mitral valve disease; only 5 had isolated mitral stenosis. Alhan,<sup>12</sup> Kayacioglu,<sup>15</sup> and their respective colleagues compared the 6-month and 8-year results of MVR either with or without chordal preservation, as performed in 30 patients who had presented with mitral stenosis and preserved LV function. They showed that MVR with preservation of chordae tendinae can be expected to have a beneficial effect on postoperative LV performance in mitral stenosis patients. In another study, Soga and associates<sup>13</sup> reported the results of chordal-sparing MVR performed by using artificial chordae in 17 patients who presented with rheumatic mitral stenosis and preserved LV systolic function. At 14 months' follow-up, the LV dimensions and the LVEFs of patients who had undergone chordal-sparing MVR were comparable to their preoperative levels. Sugita and coworkers<sup>16</sup> also examined the role of preservation of continuity between the mitral annulus and papillary muscle by using either autologous or artificial chordae on LV performance in patients with mitral stenosis. After 3.1 to 6.5 years of follow-up, they concluded that MVR with preservation of continuity between the mitral annulus and papillary muscle improves LV systolic performance. In the present study, we used a PMR technique to preserve the subvalvular apparatus and, after an 18-month follow-up, showed the superiority of this

**TABLE III.** Longitudinal Changes in the PMR Group during Follow-Up

Variable	Preoperative	Early Postoperative	Late Postoperative	P for Trend
Preoperative NYHA class				<0.001
I	—	16 (34)	33 (69)	—
II	7 (15)	5 (10)	15 (31)	—
III	41 (85)	27 (56)	—	—
LVEDD, cm	4.92 ± 0.74	4.87 ± 0.71	4.76 ± 0.72	<0.001
LVESD, cm	3.31 ± 0.7	3.26 ± 0.65	3.19 ± 0.65	<0.001
LVEF	0.54 ± 0.09	0.55 ± 0.09	0.58 ± 0.09	<0.001
LVSI	0.53 ± 0.03	0.51 ± 0.02	0.43 ± 0.04	<0.001
SPAP, mmHg	56.73 ± 15.57	36.02 ± 9.8	32.1 ± 5.78	<0.001

LVEDD = left ventricular end-diastolic dimension; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic dimension; LVSI = left ventricular sphericity index; NYHA = New York Heart Association; PMR = papillary muscle repositioning; SPAP = systolic pulmonary artery pressure

Data are presented as mean ± SD or as number and percentage. P values were calculated by repeated-measures analysis of variance.

**TABLE IV.** Longitudinal Changes in the MVR-Only Group during Follow-Up

Variable	Preoperative	Early Postoperative	Late Postoperative	P for Trend
Preoperative NYHA class				<0.001
I	—	15 (22)	45 (67)	—
II	10 (15)	6 (9)	21 (31)	—
III	57 (85)	46 (69)	1 (2)	—
LVEDD, cm	4.67 ± 0.74	4.63 ± 0.74	4.7 ± 0.76	0.09
LVESD, cm	3.12 ± 0.71	3.08 ± 0.73	3.16 ± 0.75	0.016
LVEF	0.57 ± 0.09	0.56 ± 0.09	0.55 ± 0.11	0.023
LVSI	0.54 ± 0.03	0.53 ± 0.03	0.46 ± 0.04	<0.001
SPAP, mmHg	56.51 ± 11.53	40.75 ± 16.75	30.33 ± 6.46	<0.001

LVEDD = left ventricular end-diastolic dimension; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic dimension; LVSI = left ventricular sphericity index; MVR = mitral valve replacement; NYHA = New York Heart Association; SPAP = systolic pulmonary artery pressure

Data are presented as mean ± SD. P values were calculated by repeated-measures analysis of variance.

approach to conventional MVR in reducing LV dimensions and LVSI, and in increasing LVEF.

In patients with isolated mitral stenosis, there is controversy on systolic performance of the LV. Old studies showed that rheumatic disease alters the LV geometry and that the rheumatic inflammatory process is present not only in the valves but in the myocardium.<sup>17,18</sup> However, Gash and co-authors<sup>19</sup> proposed that mitral stenosis patients as a group have reduced ejection performance—due not to impaired LV muscle function, but to increased afterload and inadequate Frank-Starling compensation. Immobility of the posterobasal LV myocardium and right ventricular enlargement are other suggested contributors to the low systolic performance observed in mitral stenosis.<sup>20</sup> Hypothetically, elimination of the filling problems and removal of the diseased subvalvular apparatus by MVR would help to improve

the systolic performance of the LV in mitral stenosis. However, experimental data have shown that interruption of the continuity between the mitral annulus and papillary muscles leads to deterioration of LV systolic function even in normal hearts.<sup>13,21</sup> Therefore, preservation of the subvalvular apparatus could also optimize postoperative LV systolic function in mitral stenosis patients. Of several studies grounded on this assumption, most have shown improvement in postoperative outcome through subvalvular-apparatus preservation, as did our study.<sup>5,22,23</sup>

Several different subvalvular-preservation techniques have been described.<sup>6-9</sup> Some authors advocate complete preservation of the mitral valve apparatus over partial preservation.<sup>16,24</sup> In an experimental study, Hansen and associates<sup>25</sup> proposed that the apparatus of the anterior leaflet is more important than that of the posterior

**TABLE V.** Comparison of the Magnitude of the Changes from Baseline to 18-Month Follow-Up Evaluation

Variable	PMR Group (n=48)	MVR-Only Group (n=67)	P Value
Decrease in LVEDD	0.16 ± 0.12	-0.04 ± 0.13	<0.001
Decrease in LVESD	0.12 ± 0.14	-0.58 ± 0.15	<0.001
Increase in LVEF	3.65 ± 6.09	-1.87 ± 6.08	<0.001
Decrease in LVSI	0.1 ± 0.04	0.08 ± 0.02	0.002
Decrease in SPAP	24.71 ± 11.72	26.18 ± 7.73	0.156

LVEDD = left ventricular end-diastolic dimension; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic dimension; LVSI = left ventricular sphericity index; MVR = mitral valve replacement; PMR = papillary muscle repositioning; SPAP = systolic pulmonary artery pressure

Data are presented as mean ± SD. *P* < 0.05 was considered statistically significant.

leaflet; however, another experimental study found no substantial difference between anterior and posterior chordal-sparing techniques.<sup>8</sup> Athanasiou and co-authors<sup>26</sup> published a meta-analysis that compared the outcomes of MVR with and without subvalvular-apparatus preservation (1,603 patients and 1,330 patients, respectively). This analysis suggested that preservation is superior to nonpreservation in regard to the perioperative mortality rate and the 1- and 5-year survival rates; further, it found no significant difference, in any of the outcomes of interest, between bileaflet and posterior leaflet preservation groups. Preservation of the subvalvular apparatus appears to be more important than the technique used to establish preservation.

In patients with mitral regurgitation, complete preservation of the mitral valve apparatus—using native tissue only—is relatively easy to accomplish, because the disease affecting the subvalvular apparatus is generally mild. However, in many patients with mitral stenosis, preservation is difficult because of severe subvalvular damage (shortening, calcification, and thickening).<sup>13,16</sup> Use of a preservation technique that is simple, reproducible, and appropriate for the patient's individual anatomy, pathologic condition, and LV function is paramount.<sup>26</sup> Therefore, patients with a severely diseased subvalvular apparatus could benefit from decalcification of valve tissue,<sup>27,28</sup> use of artificial chordae,<sup>13</sup> or PMR. Chordal-sparing MVR (by use of artificial chordate) can be performed regardless of the severity of the subvalvular disease; however, determination of the optimal length of the artificial chordae is an important aspect of this technique.<sup>13</sup> In the present study, we reported (for the first time, to the best of our knowledge) the results of PMR in patients with mitral stenosis. We used this technique in patients with heavily diseased valves, in whom leaflets are not readily amenable to preservation. Although we could have performed PMR in all patients assigned to the PMR group, it should be kept in mind that repositioning must not be performed in patients whose papillary muscles are severely retracted

and shortened. Therefore, surgeons should be familiar with more than one technique for mitral valve apparatus preservation.<sup>27</sup>

### Study Limitations

Because the type of the surgery was at the surgeon's discretion, to be decided upon exploration of the valve, this is not a randomized study. The consequences of selection bias can of course be profound in a nonrandomized study. Other major limitations are small patient numbers and lack of long-term follow-up.

### Conclusion

We conclude that papillary muscle repositioning is an effective subvalvular apparatus preservation method in rheumatic mitral stenosis patients who have preserved left ventricular systolic function but need entire resection of the mitral valve leaflets. In such patients, the addition of papillary muscle repositioning to valve replacement with a mechanical prosthesis improves left ventricular dimensions, ejection fraction, and sphericity index at the 18-month follow-up with no substantial undesirable effect on the surgery-related factors. Such repositioning is easily performed in suitable patients and does not require substantial additional time.

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