Papillary Muscle Repositioning in Mitral Valve Replacement in Patients With Left Ventricular Dysfunction

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Background. **The aim of this study was to investigate the feasibility of performing papillary muscle repositioning for mitral valve replacement procedures in patients with left ventricular dysfunction and to determine the early and late effects of this procedure on clinical outcome and left ventricular mechanics.**

Methods. **One hundred patients with ejection fraction less than 40, who were candidates for isolated surgical correction of mitral insufficiency, had mitral valve replacement and were prospectively randomly assigned to either total chordal-sparing or papillary muscle repositioning. Fifty subjects underwent papillary muscle repositioning (PMR group), and the remaining 50 had complete preservation of all chordal structures with mitral valve replacement (CMVR group). Echocardiography was performed preoperatively, at discharge, and after 2 years to determine dimensions, left ventricular shape, and function.**

Results. **End-diastolic and -systolic volumes decreased in both groups initially and continued to decline. Decreasing volumes, however, were more significant in the PMR group, in which the significant decrease in the sphericity index continued for another 2 years. In contrast, the sphericity index in the CMVR group had no significant changes at discharge and at 2 years. In terms of systolic performance, ejection fraction had no significant changes in the CMVR group, whereas ejection fraction significantly increased in the PMR group.**

Conclusions. **Papillary muscle repositioning may result in more favorable left ventricular remodeling compared with complete retention of the mitral subvalvular apparatus during mitral valve replacement. It confers a significant early and late advantage by causing significant reductions in the left ventricular chamber volume, sphericity index, and systolic performance.**

(Ann Thorac Surg 2007;83:958–63)

Chronic mitral regurgitation imposes a volume load on the left ventricle, in response to which the left ventricle initially empties more completely. Over time, left ventricular dilation maintains a normal forward cardiac output despite the regurgitant flow into the left atrium in systole. Left ventricular contractility is irreversibly impaired in the absence of symptoms in some patients [1, 2], rendering those candidates for mitral valve surgery with some degree of left ventricular systolic dysfunction.

Echocardiographic preoperative ejection fraction and systolic diameter can be predictive of postoperative ejection fraction [3]. After surgical correction of mitral regurgitation, left ventricular dysfunction is frequent and carries a poor prognosis.

We introduce a new papillary muscle repositioning technique for subvalvular-sparing mitral valve replacement procedures in an left ventricular dysfunction population and evaluate the early and late effects of this procedure on clinical outcome and left ventricular mechanics.

Accepted for publication Aug 28, 2006.

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Patients and Methods

Between February 2001 and June 2003, 100 patients with left ventricular dysfunction, who were candidates for mitral valve replacement due to chronic mitral regurgitation at Day General Hospital in Tehran, were prospectively randomized into either complete (anterior and posterior) chordal preservation mitral valve replacement (CMVR) or papillary muscle repositioning (PMR) groups.

Mitral valve involvement in our subjects was, in order of frequency, degenerative (myxomatous and nonmyxomatous, n = 81) or rheumatic (n = 19) disease (Table 1). Random allocation of the patients to either the CMVR or PMR group was dependent upon the surgeon's intraoperative decision to perform mitral valve replacement; the surgical ward secretary, having already been given 100 envelopes numbered from 1 to 100—the even numbers for CMVR and the odd numbers for PMR—would then give the surgeon one of these numbers at random. Fifty of these subjects underwent complete chordal preservation (CMVR group), and 50 had papillary muscle repositioning (PMR) for preservation of the mitral subvalvular apparatus. All the patients had an ejection fraction of less than 40%, and all the valves were deemed to be irreparable at the time of surgery by the surgeon. Our exclusion

Published by Elsevier Inc

0003-4975/07/$32.00
doi:10.1016/j.athoracsur.2006.08.045

criteria were ischemic mitral regurgitation (to avoid interference between our results and those of coronary complications), evidence of coronary artery disease, substantial mitral stenosis (mean transvalvular gradient > 5 mm Hg), and need for other surgical procedures. Informed consent was obtained from all the patients, and the protocol was approved by our Review Board.

Surgical Technique

Standard moderate hypothermic (approximately 28°C to 32°C) cardiopulmonary bypass was used. Cold hyperkalemic cardioplegia, delivered both through antegrade and retrograde routes, was utilized to ensure myocardial protection.

Although preoperative echocardiography was indicative of the irreparability of all the valves, the surgeon's final intraoperative assessment of the valve would decide between mitral valve repair and replacement. In those patients having been randomly assigned to the complete chordal preservation group, the entire subvalvular apparatus was preserved in anatomic fashion. The posterior leaflet and its chordal attachments were preserved. If the posterior leaflet was excessively redundant or the chordae tendineae were elongated, the leaflet was imbricated into the mitral annulus with the valve sutures. The anterior leaflet was detached 3 to 4 mm from the annulus, and a central elliptical portion was excised, leaving a 5- to 8-mm rim of leaflet-free edge, which was attached to the primary (first order or marginal) chordae tendineae. This strip of the leaflet was then reattached to the annulus in the corresponding location with the valve sutures (Khonsari II technique). Alternatively, if the anterior leaflet was excessively redundant, it was divided into 2 to 4 segments, which were afterward resuspended in a normal anatomic position with the valve sutures (Khonsari I technique).

Table 1. Type of Mitral Valve Involvement in Both Groups

	Group	
	CMVR	PMR
Type		
Degenerative nonmyxomatous		
Count	11	11
%	22.0%	22.0%
Degenerative myxomatous		
Count	28	31
%	56.0%	62.0%
Rheumatic		
Count	11	8
%	22.0%	16.0%
Total		
Count	50	50
%	100.0%	100.0%

Type of surgery had no significant statistical difference in both groups, $p = 0.731$.

CMVR = complete chordal preservation mitral valve replacement; PMR = papillary muscle repositioning.

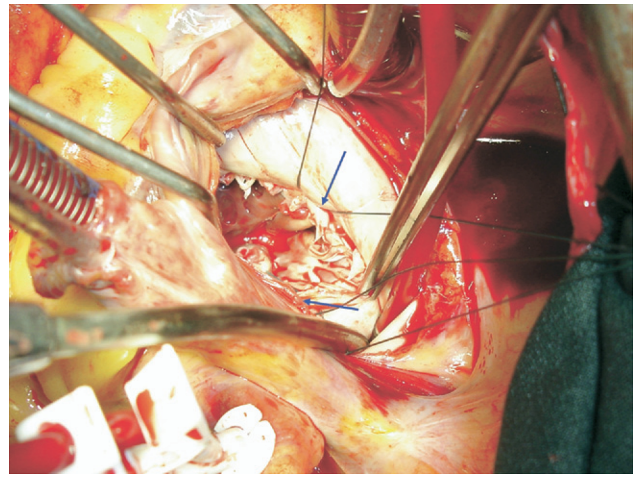

Fig 1. The head of both papillary muscles (arrow) was sutured to annulus on the posterior side.

In the patients having been randomly allocated to the papillary muscle repositioning group, leaflets were excised from base (2 mm from annulus), and all of the native chordal structures were resected. Subsequently, the heads of both papillary muscles were sutured with a 2-0 Ethibond (Ethicon Inc, Somerville, NJ) to the posterior side of the corresponding annulus, leaving no space between the heads of the papillary muscles and the annulus. If the papillary muscle had fibrous tissue, a suture of 2-0 Ethiband on a double-armed needle was sewn to the fibrous tip. If there was no fibrous tissue, the suture was buttressed with a small soft felt pledget or pericardium and was tied snugly. Both needles of each suture were then passed through the annulus of the mitral valve at the roughly 4 and 8 o'clock positions. Finally, the valve was implanted on the annulus, so that the heads of the papillary muscles were directly underneath the ring of the prosthetic valve (Fig 1).

Either St. Jude (St. Jude Medical, St. Paul, Minnesota) or On-X (Medical Research Institute, Austin, Texas) mechanical prostheses (33 mm, 26 patients; 31 mm, 40 patients; 29 mm, 24 patients; and 27 mm, 10 patients) were used in all the patients, without significant changes between the two groups.

Transesophageal echocardiography examination was routinely done during the operations. Both leaflets of the prostheses were freely mobile without any limitation in all the patients. There was no left ventricular out flow tract obstruction or prosthesis-related complication in either group.

Echocardiographic Studies

Two-dimensional, M-mode, and color-flow Doppler echocardiography with standard acoustic windows using a GE Medical System (Vivid 7; General Electric, Horton, Norway) were performed in all the patients preoperatively (transthoracic echocardiography), intraoperatively (transesophageal echocardiography), and postoperatively (transthoracic echocardiography) first at hospital discharge and then 2 years afterward. Intraoperative echocardiographic measurements were made possible by maintaining an acceptable level of blood volume, blood pressure, and heart rate after our patients had been weaned off the bypass. Upon the completion of the study, all the results were read by two observers in a blinded fashion. Mean values for each measurement were derived from 3 consecutive heart beats in the patients in sinus rhythm and from 5 beats in those in atrial fibrillation. Of a total of 100 cases, we only had 5 patients lost to follow-up: 2 of them had died, and we lost track of the other 3.

Ejection fraction was computed by means of left ventricular end-diastolic and end-systolic volume, utilizing Simpson's method.

The left ventricular sphericity index was calculated as the ratio of the left ventricular internal diameter in short axis compared with the left ventricular length (measured as the distance from the mitral annulus to the apical endocardium in the left ventricular long axis view).

Echocardiographic data were measured according to the criteria of the American Society of Echocardiography.

Statistical Analysis

Data are expressed as mean and standard deviation (SD). Data comparisons between the two groups were performed by unpaired *t* test. Longitudinal changes in the variables were compared between the two groups by two-way analysis of variance with repeated measurements.

All the statistical analyses were performed using the SPSS version 11.0 program (SPSS, Chicago, Illinois). A significance level of p less than 0.05 was used for all the comparisons.

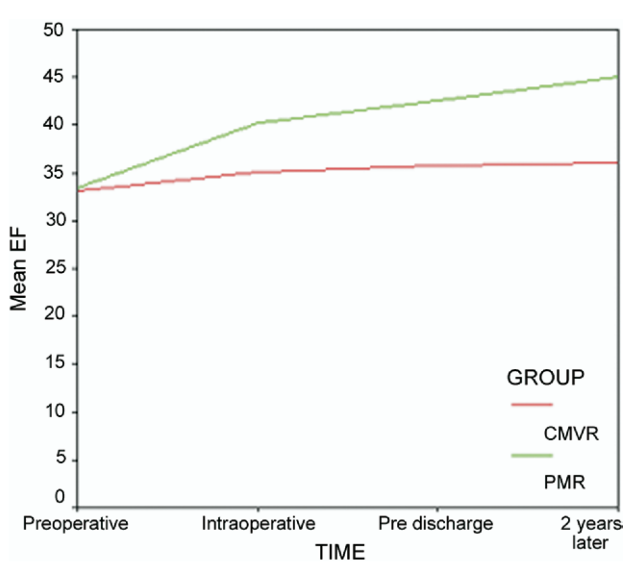

Fig 2. Changes in left ventricular ejection fraction (EF) according to the type of surgery: complete chordal preservation mitral valve replacement (CMVR [red line]) or papillary muscle repositioning (PMR [green line]).

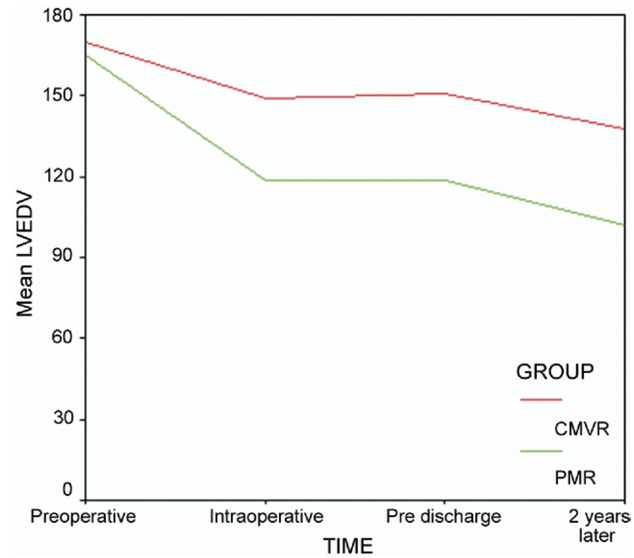

Fig 3. Changes in left ventricular end-diastolic volume (LVEDV) according to the type of surgery: complete chordal preservation mitral valve replacement (CMVR [red line]) or papillary muscle repositioning (PMR [green line]).

Results

Our patients had degenerative (myxomatous and non-myxomatous) or rheumatic changes of the mitral leaflets and subvalvular apparatus. Although there was a greater percentage of male patients in the PMR group (58% male in the PMR group and 50% in the CMVR group, p = 0.422), no differences were noted in terms of age (mean age in PMR group, 45.7 ± 9.1 years, and in CMVR group, 46.2 ± 8.1; p = 0.890), ejection fraction, left ventricular end-systolic and end-diastolic volumes, sphericity index, and preoperative New York Heart Association classification. Selected patient characteristics in accordance with the operative procedure groups are summarized in Table 1.

There was neither operative nor hospital mortality. However, 1 patient in the CMVR group died of trauma, and 1 patient in the PMR group died of pulmonary infection and respiratory failure 2 months after surgery. No bleeding and thrombosis or embolic complications were found over the follow-up period.

Cross-clamp period in the PMR group was no longer than that in conventional MVR operations. The mean aortic cross-clamp time was 30.0 ± 10 minutes in the CMVR group and 32.0 ± 12 minutes in the PMR group. The cardiopulmonary bypass time was 40 ± 11 minutes and 41 ± 14 minutes in the CMVR and PMR groups, respectively.

As regards ejection fraction (%), there was a sudden increase demonstrated by intraoperative transesophageal echocardiography in the PMR group from a preoperative 33.4 ± 5.2 to 40.20 ± 5.25, which was confirmed by the continuous slight increase in postoperative transthoracic echocardiography (42.5 ± 5) at discharge and 2 years afterward (44.9 ± 3.2). In the CMVR group, however, ejection fraction increased slightly from 33.1 ± 5.4 to

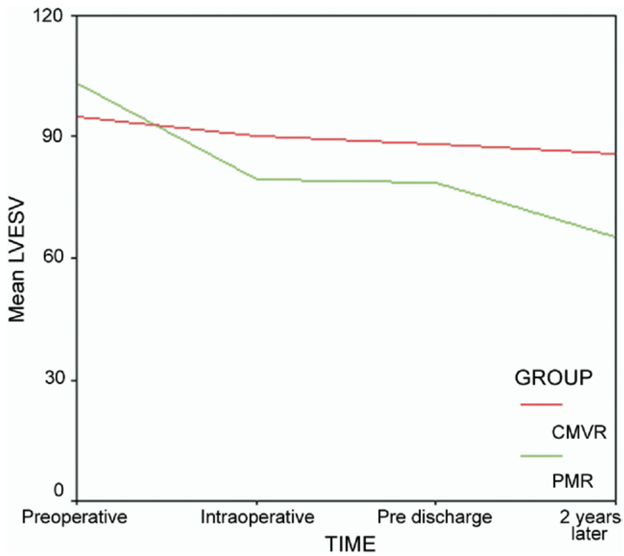

Fig 4. Changes in left ventricular end-systolic volume (LVESV) according to the type of surgery: complete chordal preservation mitral valve replacement (CMVR [red line]) or papillary muscle repositioning (PMR [green line]).

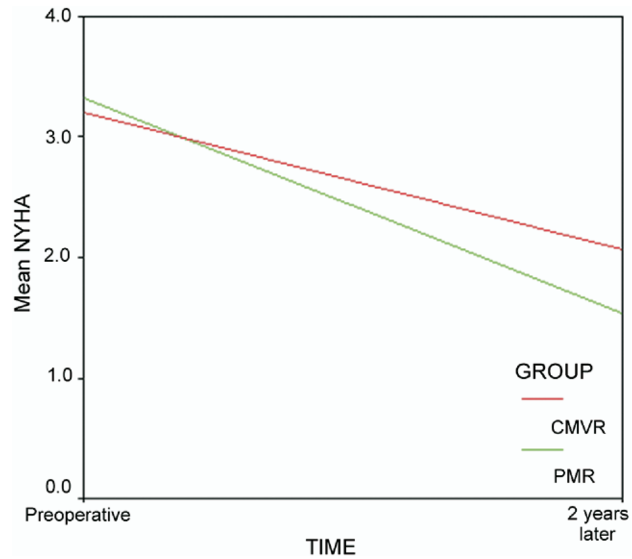

Fig 6. Changes in New York Heart Association (NYHA) according to the type of surgery: complete chordal preservation mitral valve replacement (CMVR [red line]) or papillary muscle repositioning (PMR [green line]).

35.10 ± 4.34 intraoperatively; this trend continued from 35.7 ± 4.9 predischarge to 36.2 ± 4.4 after 2 years. It was noted that whereas ejection fraction had no significant changes in the CMVR group, it exhibited a significant increase in the PMR group (Fig 2).

Echocardiographically, the PMR group demonstrated a statistically more significant improvement in their left ventricular diastolic and systolic volumes in comparison with the CMVR group. The initial decline in end-diastolic and end-systolic volumes in both groups was sustained; nevertheless, the decrease in volumes was more significant in the PMR group (Figs 3 and 4). The sphericity index significantly decreased initially, and this trend continued for 2 years. In contrast, the sphericity index in the CMVR group had no significant changes at discharge and after 2 years (Fig 5).

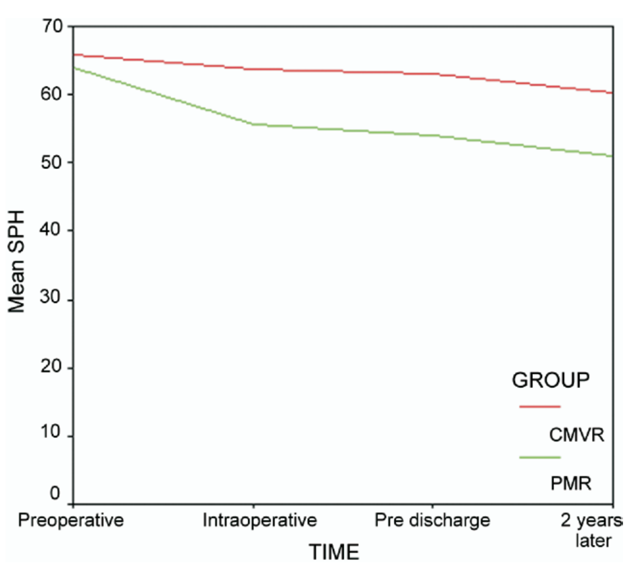

Fig 5. Changes in sphericity index SPH according to the type of surgery: complete chordal preservation mitral valve replacement (CMVR [red line]) or papillary muscle repositioning (PMR [green line]).

The rapid changes in the PMR group during surgery and at discharge demonstrate that the physical tethering of the papillary muscles to pull the left ventricle into an improved shape results in a better ventricular dynamic. Patients undergoing PMR derived greater functional benefits than did patients undergoing CMVR. New York Heart Association classification was better in the PMR group after 2 years, changing from 3.2 to 2 in the CMVR group, and from 3.3 to 1.5 in the PMR group (Fig 6).

Comment

Today, there is increasing awareness that left ventricular dysfunction may silently progress in the asymptomatic patient, and that objective signs of dysfunction may not be manifested until late in the disease process. This silent progression may result in delayed surgical intervention, thereby worsening the long-term surgical outcome [4–6].

Despite this, ejection fraction is one of the most important determinants of long-term survival after mitral valve surgery for mitral regurgitation. Patients with normal preoperative ejection fraction have an excellent postoperative survival, whereas patients with moderate to severely reduced ejection fraction are at considerable risk [3–8].

Mitral valve surgery for the correction of mitral regurgitation in patients with left ventricular dysfunction has long been associated with a poor outcome, with numerous studies identifying a depressed left ventricular ejection fraction as a poor prognostic indicator [3–8]. These

Table 2. Patient Characteristics According to Operative Procedure Groups

Group	Preoperative Mean (SD)	Intraoperative Mean (SD)	Predischarge Mean (SD)	2 Years Later Mean (SD)	*p* Value
EF					0.000
CMVR	33.10 (5.43)	35.10 (4.34)	35.70 (4.95)	36.20 (4.47)	
PMR	33.40 (5.29)	40.20 (5.25)	42.50 (5.08)	44.90 (3.27)	
LVEDV					0.000
CMVR	169.76 (30.87)	149.12 (27.95)	150.64 (27.84)	137.92 (25.34)	
PMR	164.94 (30.33)	118.66 (20.35)	118.58 (20.92)	102.24 (16.63)	
LVESV					0.000
CMVR	94.98 (20.17)	90.12 (17.58)	88.32 (16.37)	84.92 (15.66)	
PMR	103.40 (17.98)	79.36 (13.54)	78.80 (13.79)	66.04 (12.64)	
SPH					0.000
CMVR	65.84 (5.29)	63.84 (4.30)	63.16 (4.79)	60.26 (4.53)	
PMR	63.90 (4.99)	55.62 (4.15)	54.08 (4.09)	50.86 (3.27)	
NYHA					0.000
CMVR	3.20 (0.61)			2.06 (0.74)	
PMR	3.32 (0.65)			1.54 (0.65)	

CMVR = complete chordal preservation mitral value replacement; EF = ejection fraction; LVEDV = left ventricular end diastolic volume; LVESV = left ventricular end systolic volume; NYHA = New York Heart Association; PMR = papillary muscle repositioning; SPH = sphericity index.

observations have been largely made in the case of traditional mitral valve replacement, causing the disruption of the subvalvular apparatus. Lillehei and colleagues [9] were the first to describe the importance of conservation of the subvalvular apparatus in the preservation of systolic function. The early [10–12] and late [13–15] hemodynamic benefits of preserving the mitral subvalvular apparatus during mitral valve replacement have been demonstrated in several studies.

Some studies, such as that by Okita and associates [16, 17], favor the replacing of chordae tendineae; however, we would suggest the complete removal of chordae tendineae.

The irreversible left ventricular changes in the wake of significant remodeling of the ventricle thwarted surgeons' previous attempts at averting a decrease in ejection fraction by preserving the patient's subvalvular apparatus, and that prompted us to demonstrate that our technique helps the left ventricle remodel to a smaller and more ellipsoid ventricle, with an increase in ejection fraction and decrease in the sphericity index postoperatively.

Our findings suggest that the repositioning of papillary muscles results in more favorable left ventricular geometry and its concomitant improvement in ventricular remodeling and ejection performance even at 2 years. We would, therefore, recommend that papillary muscle repositioning be performed if mitral valve replacement is necessary so that early postoperative and late left ventricular systolic functions can be optimized.

We maintain that not only is this management strategy important for patients with mitral regurgitation of a valvular etiology, but also it can be extended to mitral regurgitation of a ventricular etiology in patients with functional mitral regurgitation. As mitral regurgitation is commonly associated with dilated cardiomyopathy, PMR could be an integral part of the management of patients whose mitral valve is irreparable. This, we maintain, is achieved partly by the preservation of the subvalvular apparatus during replacement and partly by the correction of the volume overload in the left ventricle and better left ventricular shape, allowing a more gradual physiologic remodeling than that achieved by, for example, left ventriculectomy.

Weconclude that our technique for reshaping the left ventricle during mitral valve replacement can be accomplished safely, with excellent results in patients with mitral regurgitation and left ventricular dysfunction.

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INVITED COMMENTARY

This study [1] is a refreshingly high-quality randomized trial with blinded echocardiographic review. The technique described is potentially applicable to routine mitral replacement. Chordal preservation (ie, preservation of the posterior leaflet chords in particular) has been shown to essentially eliminate the dreaded complication of ventricular-annular separation. Chordal preservation has also been shown to better preserve ventricular function and dimensions compared with chordal resection. Yet in many cases in which the posterior leaflet or annulus, or both, are involved with bulky disease, chordal preservation can be difficult at best. The papillary muscle repositioning technique described here could potentially replace or supplement chordal preservation in these difficult cases.

Optimizing suture length has been difficult while placing artificial chords in mitral repair. Similarly, achieving the correct distance or tension between the base of the papillary muscle and the annulus could be challenging in the papillary muscle repositioning technique, especially given that the lengths of the resected chords of the papillary muscles themselves can vary. Yet, by simply attaching the heads of the papillary muscles to the annulus, the authors reported no such problems. As has been seen in left ventricular aneurysm resection, leaving the left ventricular cavity too small with papillary muscle repositioning could theoretically impair stroke volume, whereas leaving the distance from the annulus to the base of the papillary muscle excessively long may be of little benefit.

Why sutures were better than native chords in this study is unclear. It is likely that the authors reduced cavitary volume by reducing the distance from the base of the papillary muscle to the annulus with the papillary muscle repositioning technique. It may be important that this series examined only patients with left ventricular ejection fraction less than 40% and mitral regurgitation. Whether the technique would apply to patients with mitral stenosis or normal left ventricular function is unclear. This series is also too small to know whether papillary muscle repositioning will eliminate ventricular-annular separation, and the 2-year intermediate-term results will need to be supplemented with longer term follow-up. The authors are nonetheless to be congratulated for an intriguing, well-designed study that could benefit many patients.

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0003-4975/07/$32.00
doi:10.1016/j.athoracsur.2006.09.066