Randomized Trial of Partial Versus Complete Chordal Preservation Methods of Mitral Valve Replacement

A Preliminary Report

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**Background**—The merits of retaining the subvalvular apparatus during mitral valve replacement for chronic mitral regurgitation have been demonstrated in numerous clinical and laboratory investigations. In this preliminary report, we analyzed the early effects of complete versus partial chordal preservation on left ventricular mechanics.

**Methods and Results**—Fifty patients undergoing isolated surgical correction of mitral insufficiency were prospectively randomized to either total or partial chordal-sparing mitral valve replacement. Of the first 19 patients studied, 8 had preservation of the posterior leaflet only, and 11 had complete preservation of all chordal structures. A comparison group consisted of 6 patients who had primary mitral valve repair. Echocardiography was performed preoperatively and at discharge from the hospital to determine dimensions, wall stress, and ejection fraction. Preservation of the posterior leaflet only resulted in a reduction in end-diastolic volume, an increase in end-systolic volume \( (P=0.058) \), a rising trend in end-systolic stress, a decrease in long-axis fractional shortening, and a fall in ejection fraction from \( 0.68 \pm 0.16 \) to \( 0.46 \pm 0.19 \) \( (P=0.001) \). Although patients who had preservation of all chordal structures also had decreased end-diastolic volume, long-axis fractional shortening, and ejection fraction \( (0.60 \pm 0.13 \) to \( 0.52 \pm 0.07 \), \( P=0.01) \), end-systolic stress fell and end-systolic volume decreased instead of increased. Compared with the posterior leaflet preservation group, those in the group with completely preserved chordal structures had a larger decline in end-diastolic volume and smaller decreases in long-axis fractional shortening and ejection fraction. Changes in end-systolic volume and stress were also statistically different between the 2 cohorts. No differences were detected between the group with total preserved chordal structures and the mitral repair group in any of the measured parameters.

**Conclusions**—Compared with posterior chordal preservation only, complete retention of the subvalvular apparatus during mitral valve replacement resulted in improved ejection performance and smaller chamber volumes due to reduced systolic wall stress. These hemodynamic advantages are comparable to those observed with primary mitral reconstruction. *(Circulation. 1999;100[suppl II]:II-90–II-94.)*

**Key Words:** mitral valve ■ hemodynamics ■ surgery ■ physiology

Preservation of the mitral subvalvular apparatus has been demonstrated in several studies to improve postoperative left ventricular (LV) systolic performance in patients with mitral valve replacement (MVR).\(^1\)\(^–\)\(^3\) The issue of complete versus partial chordal preservation, however, has not been specifically addressed in the clinical setting despite several laboratory investigations\(^4\)\(^–\)\(^6\) demonstrating its superiority in normal canine hearts. As a result, many surgeons continue to preserve only the posterior leaflet chordae tendineae because of concerns over greater technical complexity, longer operating time, potential interference with mechanical valve leaflet motion, the need to undersize the mitral prosthesis, and the possibility of creating LV outflow tract obstruction.\(^7\) In this report, we prospectively analyzed LV systolic mechanics in patients randomized to receive either complete (bileaflet) or partial (posterior leaflet only) chordal sparing during MVR for isolated mitral regurgitation. The results were compared with a contemporary cohort of persons who underwent mitral valve repair.

**Methods**

Between June 1996 and July 1997, 50 patients undergoing MVR for chronic mitral regurgitation at Southern California Kaiser Permanente Medical Center in Los Angeles were prospectively randomized to either partial (posterior leaflet) or complete (anterior and posterior) chordal preservation groups. The surgeon deemed all valves nonrepairable at the time of operation. Those with evidence of coronary artery disease or substantial mitral stenosis (mean transvalvular gradient >5 mm Hg) were excluded. Of the first 19 patients...
studied, 8 underwent partial MVR (P-MVR), and 11 had complete MVR (C-MVR) preservation of the mitral subvalvular apparatus. Thus, the following data represent a preliminary analysis of the original larger trial. Six similar patients from Stanford who were undergoing mitral valve repair by 1 surgeon (D.C.M.) during this same time frame were studied for comparison. The protocol was approved by our institution’s investigational review board.

### Surgical Techniques

Standard moderate hypothermic (1–2°C) cardiopulmonary bypass was used. Myocardial protection consisted of intermittent antegrade and/or retrograde cold hyperkalemia cardioplegia. Sixteen St. Jude (St. Jude Medical, Inc) bileaflet mechanical prostheses (10 for C-MVR, 6 for P-MVR) and 3 Hancock (Medtronic, Inc) porcine valves (1 for C-MVR, 2 for P-MVR) were inserted. In patients randomized to the P-MVR technique, the anterior leaflet and its attached chordae tendineae were excised. 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. In those randomized to complete chordal preservation, the entire subvalvular apparatus was preserved in an anatomic fashion as described by Sintek and associates. Briefly, the anterior leaflet was detached 3 mm from the annulus and a central elliptically shaped portion excised, leaving a 5- to 10-mm rim of leaflet free edge attached to the primary (first-order or marginal) chordae tendineae. This strip of 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 then resuspended in a normal anatomic position with the valve sutures (Khonsari I technique). Patients undergoing mitral valve repair primarily underwent quadrilateral resection of ≥1 of the posterior leaflet scallops, plication of the mitral annulus, and annular reinforcement with a Cosgrove annuloplasty ring (Baxter Healthcare Corporation).

### Echocardiographic Studies and Measurements

Two-dimensional, M-mode, color flow Doppler transthoracic echocardiography was performed by the same respective technician at each institution in all patients just before surgery and at hospital discharge by use of standard acoustic windows. The quality and consistency of all studies were confirmed by 1 author (A.D.F.) and each institution in all patients just before surgery and at hospital discharge by 1 observer (M.R.Z.) in a blinded fashion. End diastole was defined as the onset of the ECG Q wave and end systole as the time of minimum LV dimension. Instantaneous LV volume (V) was calculated as $V = \frac{4}{3} \pi D_0 L$, where D is the LV minor axis dimension acquired from the short-axis view and L is the long-axis dimension acquired from the apical 4-chamber view. Ejection fraction (EF) was computed with LV end-diastolic (EDV) and end-systolic (ESV) volumes. Similarly, long-axis fractional shortening (LAFS) was determined by use of end-diastolic and end-systolic long-LV-axis dimensions. Mid-wall circumferential end-systolic LV stress (ESS), a clinically useful estimate of LV afterload, was calculated by Mirsky’s formula for a prolate ellipsoid as $ESS = \frac{Pb}{h(1-h^2)}$, where $P = 0.98$ times the mean arterial (cuff) pressure plus 11 mm Hg, $h$ is the end-systolic wall thickness, b is the end-systolic semi-minor axis ($D+h/2$), and a is the end-systolic semi-major axis ($L+h/2$). Mean arterial cuff pressure was defined as $\text{ystolic blood pressure} + 2 \text{ diastolic blood pressure}/3$.

### Statistical Analysis

All data are expressed as mean±1 SD unless otherwise specified. Preoperative demographic characteristics of each surgical group were compared by use of the contingency table for categorical variables and ANOVA for continuous variables. Two-way repeated-measures ANOVA was used to assess the influence of time (preoperative versus postoperative) and type of procedure (P-MVR versus C-MVR versus repair) on all echocardiographically derived param-

### Results

Selected preoperative patient characteristics are summarized according to operative procedure group in Table 1.

<table>
<thead>
<tr>
<th>Procedure Type</th>
<th>Repair (n=6)</th>
<th>P-MVR (n=8)</th>
<th>C-MVR (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65±16</td>
<td>62±14</td>
<td>54±14</td>
</tr>
<tr>
<td>Male sex</td>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>NYHA class</td>
<td>2.3±0.5</td>
<td>2.8±0.7</td>
<td>2.9±0.8</td>
</tr>
<tr>
<td>Etiology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rheumatic</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Prolapse</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Degenerative</td>
<td>5</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Endocarditis</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

NYHA indicates New York Heart Association. Values are mean±1 SD.

The echocardiographically measured EDV, ESV, ESS, EF, and LAFS values are shown in Table 2. Two-way repeated-measures ANOVA demonstrated a significant decline in EDV and EF in all 3 groups. Reductions in LAFS were also observed in all groups, but this was only possibly significant in the repair cohort (P=0.12). By discharge, LAFS was significantly lower in those with only P-MVR compared with the other 2 groups (P<0.05). In contrast, although ESV and ESS fell in both the repair and C-MVR groups, it increased in patients with P-MVR; in those with mitral repair, these changes did not achieve statistical significance. For each of the 5 echocardiographic measurements, there was a statistically significant interactive effect between time and the procedure group.

To further evaluate the changes in parameters between groups, the differences were expressed as fractional change: percent change between the preoperative and early postoperative values was computed. As shown in Figure 1, there was a smaller reduction in EDV and greater declines in LAFS and EF in the P-MVR group than in the C-MVR and repair cohorts. Furthermore, in the P-MVR group, ESV and ESS increased rather than decreased, as was seen in the repair and C-MVR groups.

### Discussion

Numerous clinical studies have examined the effects of MVR (with or without chordal preservation) and mitral valve repair on LV volumes and systolic dynamics. The results have been mixed, perhaps due to the retrospective nature of the inves-

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tigations, heterogeneous patient populations, and the absence of controlled, randomized trials. Consistent with our findings, others have almost uniformly reported decreases in EDV after mitral repair\textsuperscript{1,2,11–13} or replacement whether or not the chordae are preserved.\textsuperscript{2,14–21} Similarly, previous reports have also noted a decline in ESV after MVR with complete preservation of the subvalvular apparatus\textsuperscript{1,2,10,16,22}; although a lower ESV is usually observed postoperatively after mitral repair,\textsuperscript{1,11,12} we only found a trend in this direction (but the number of patients was very small). This is concordant with the findings of Okita and coworkers.\textsuperscript{2} In our study, patients undergoing MVR with resection of the anterior leaflet and its chordae (P-MVR group) had an increase in ESV, which differs from the 2 previous investigations.\textsuperscript{16,23} Although Ghosh and colleagues\textsuperscript{23} reported a fall in the median LV end-systolic dimension in 37 patients undergoing posterior chordal-sparing MVR, the difference was <5\%. In a smaller cohort of 5 patients who underwent a similar type of MVR procedure, Hannein and associates\textsuperscript{16} demonstrated a significant decrease in LV end-systolic dimension from 50 to 34 mm. These follow-up measurements, however, were performed 6 to 9 months postoperatively; furthermore, these authors did not report ESS calculations, which correlated strongly with ESV in our study as well as others.\textsuperscript{2,10,15}

In this analysis, LVEF and LAFS were used as measures of LV ejection performance, but both measures are dependent on afterload and preload. The relative preservation of LAFS in the repair and C-MVR groups is likely due to maintenance of papillary-annular continuity. This is supported by other studies\textsuperscript{2,13,24} demonstrating a reduction in radial fractional shortening in the LV regions subtended by the papillary muscles. However, it was rather surprising to find a small decline in EF in all 3 groups, albeit larger in the P-MVR group. Previous reports have noted no change in EF after either mitral reconstruction\textsuperscript{1,11–13} or chordal-sparing MVR.\textsuperscript{1,2,10,14–16} However, EF is highly load-dependent\textsuperscript{25} and is a poor indicator of LV systolic function in patients with chronic mitral insufficiency secondary to the imposed abnormal loading conditions.\textsuperscript{26} Because ESS fell in the repair and C-MVR groups compared with the P-MVR cohort, the decrease in EF was not due to augmented LV afterload but rather in part secondary to the abrupt fall in EDV caused by correction of the chronic mitral regurgitation.\textsuperscript{18} Such an early postoperative fall in EDV and EF accompanied by a subse-

### Table 2. Echocardiographic Measurements by Procedure Type

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before Surgery</th>
<th>At Discharge</th>
<th>( P ) (Time)</th>
<th>( P ) (Time×Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDV, mL</td>
<td>Repair 161±62</td>
<td>98±36</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-MVR 157±76</td>
<td>135±83</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-MVR 187±32</td>
<td>129±31</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( P ) 0.46</td>
<td>0.42</td>
<td></td>
<td>0.006</td>
</tr>
<tr>
<td>ESV, mL</td>
<td>Repair 58±34</td>
<td>48±26</td>
<td>0.273</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-MVR 52±44</td>
<td>71±53</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-MVR 67±18</td>
<td>58±21</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( P ) 0.59</td>
<td>0.50</td>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td>ESS, kdyne/cm(^2)</td>
<td>Repair 120±35</td>
<td>108±31</td>
<td>0.276</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-MVR 95±45</td>
<td>106±43</td>
<td>0.250</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-MVR 118±25</td>
<td>100±25</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( P ) 0.29</td>
<td>0.85</td>
<td></td>
<td>0.032</td>
</tr>
<tr>
<td>LAFS, %</td>
<td>Repair 17±5</td>
<td>14±2(^*)</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-MVR 17±7</td>
<td>10±4</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-MVR 16±4</td>
<td>14±3(^*)</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( P ) 0.70</td>
<td>*&lt;0.05 vs P-MVR</td>
<td></td>
<td>0.013</td>
</tr>
<tr>
<td>EF</td>
<td>Repair 0.64±0.14</td>
<td>0.50±0.11</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-MVR 0.68±0.16</td>
<td>0.46±0.19</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-MVR 0.60±0.13</td>
<td>0.52±0.07</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( P ) 0.45</td>
<td>0.66</td>
<td></td>
<td>0.039</td>
</tr>
</tbody>
</table>

Values are mean±1 SD. \(^*\) These 2 LAFS groups are significantly different from P-MVR by multiple comparisons \((P<0.05)\).
quent decrease in systolic LV dimensions and recovery of EF have been demonstrated in patients undergoing aortic valve replacement for aortic regurgitation.18,27

To more comprehensively assess the effect of the different surgical techniques on LV systolic function, changes in the ESS/ESV ratio were also examined. This ratio has been reported to be a relatively less load-sensitive index of LV systolic mechanics in patients with mitral incompetence.28 This index increased by 6.7% after mitral repair, which was significantly different from the 12.9% decline in the P-MVR group (P<0.05). The ESS/ESV ratio was unchanged in the C-MVR cohort (−0.74%), which possibly was significantly different from the response in the P-MVR group (P=0.1). Okita and colleagues2 also noted higher ESS/ESV ratios in patients undergoing mitral repair and complete chordal-sparing MVR compared with those after conventional MVR, despite a fall in EF in the repair group.

Only 2 other clinical investigations10,16 have addressed the issue of C-MVR versus P-MVR in terms of LV mechanics. In a study at the National Institutes of Health,16 patients who received either posterior or bileaflet chordal-sparing MVR (compared with conventional MVR) had smaller systolic dimensions and better preservation of EF at 6 to 9 months postoperatively; however, there were no significant differences between the complete versus partial chordal preservation groups. Although not statistically significant, it should be noted that there was a trend for EF to increase after retention of the entire subvalvular apparatus. LVEF in the conventional MVR group at 6 months was significantly lower than in the bileaflet preservation MVR group but similar to the values in the group in which only the posterior chordae were preserved. When both chordal-sparing groups were combined, EF was significantly higher. Thus, it appears that there might have been some additional functional benefit when all chords were preserved. In another report by Rozich and associates,10 the superiority of chordal preservation over conventional MVR was demonstrated in terms of smaller LV dimensions, lower systolic wall stress, enhanced ejection performance, and return to a more elliptically shaped ventricle. Again, no significant differences were detected between the partial versus complete chordal preservation MVR groups. As noted by the authors, however, the number of patients in each subset was small, and the methods used to spare the chordae were varied (anterior chords were preserved in 1 patient, posterior chords in 4 patients, and all chords in 3 patients), thereby reducing the likelihood of finding a statistical difference.

Taken together, these data suggest that complete chordal preservation during MVR for chronic mitral regurgitation confers a significant advantage to the patient by reducing LV chamber size and systolic afterload and minimizing any early postoperative drop in ejection performance. Conversely, resection of the anterior chordae during MVR results in augmented systolic LV afterload, thereby reducing pump performance, ie, a larger decline in LAFS and EF and an increase in ESV.

Study Limitations
Several limitations of this study should be discussed. First, the patients in the repair group were not randomized. Such a trial is unrealistic given the overwhelming data supporting mitral reconstruction when feasible as the procedure of choice in patients with mitral regurgitation. Although MVR with chordal preservation may have comparable hemodynamic advantages over conventional MVR in terms of LV systolic performance, other beneficial effects of repair with respect to avoiding prosthetic valve–related complications have been demonstrated.3 Furthermore, the purpose of the current investigation was to examine the effects of MVR with either complete or partial chordal preservation on LV systolic mechanics. Second, the number of patients in this preliminary report was small, particularly in the repair cohort. As a result, the statistical power to detect significant differences among the groups was low. A complete analysis of all 50 patients is forthcoming to verify our current findings. Third, because myocardial muscle shortening continues beyond aortic valve closure in patients with mitral insufficiency, true ESS may have been underestimated preoperatively29; however, this does not alter our interpretations, because a higher preoperative ESS would have resulted in an even larger postoperative reduction in afterload in patients undergoing MVR with complete chordal preservation. Finally, this study did not address the effects of the various surgical techniques in patients with “decompensated” chronic mitral regurgitation due to pronounced LV failure. Although multivariable analysis has shown that preoperative LVEF may be the most significant clinical predictor of postoperative LV systolic performance3,20,21 independent of chordal preservation, others2,30 have suggested a greater importance of the mitral subvalvular apparatus in patients with more advanced LV systolic dysfunction. However, other factors may be involved, as it has been estimated from anecdotal observations that more than one third of patients develop LV failure after MVR despite retaining the primary chordal structures.31 It is likely that chordal preservation reduces the severity of postoperative LV dysfunction after MVR rather than preventing its occurrence.

In conclusion, complete retention of the mitral subvalvular apparatus during MVR improves LV ejection performance in the early postoperative period by reducing global LV afterload compared with MVR with partial (posterior leaflet) chordal preservation. When MVR is necessary, we recommend that attempts should be made to preserve all chordal structures to both the anterior and the posterior leaflet to optimize postoperative LV systolic function. Whether these hemodynamic advantages are temporary or permanent will require further long-term follow-up.

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References


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