Mitral Valve Replacement Versus Mitral Valve Repair
A Doppler and Quantitative Stress Echocardiographic Study

Marc D. Tischler, MD; Kyle A. Cooper, MD; Michaelanne Rowen, RN; Martin M. LeWinter, MD

Background Standard mitral valve replacement (MVR) in patients with chronic mitral regurgitation results in consistent reductions in resting postoperative ejection fraction. This has been attributed to removal of the low-impedance ejection pathway into the left atrium or to disruption of the chordal apparatus. Mitral valve repair (MVP) does not reduce ejection fraction at rest. However, whether MVP confers any advantages with regard to dynamic left ventricular performance has not been investigated. The aim of this study was to directly compare standard MVR with MVP and to determine their respective influences on ventricular ejection performance during bicycle exercise.

Methods and Results Ten consecutive patients with pure chronic mitral regurgitation who underwent MVP and 10 patients matched for age, sex, and preoperative ejection fraction who underwent standard MVR for pure chronic mitral regurgitation performed symptom-limited, graded upright bicycle exercise with simultaneous Doppler and quantitative two-dimensional echocardiography. Patients with MVP had significantly greater rest (55±12%) and exercise (63±11%) ejection fractions than matched patients with MVR (40±13% [P<.0001] and 42±17% [P<.005], respectively). End-systolic circumferential wall stress was significantly lower at rest (190±36 versus 244±46; P<.03) and at peak exercise (231±46 versus 300±52; P<.02) in patients with MVP. At peak exercise, left ventricular shape was significantly more spherical in patients with MVR than those with MVP (1.84±0.31 versus 2.45±0.59; P<.02).

Conclusions MVR with chordal transection resulted in significant reductions in rest and exercise ejection fraction. This was caused in part by a significant increase in end-systolic circumferential wall stress. MVP resulted in improved rest and exercise ejection indexes, primarily due to a marked reduction in end-systolic stress and maintenance of a more ellipsoidal chamber geometry. (Circulation. 1994;89:132-137.)

Key Words • exercise • echocardiography • valves • surgery

Conventional techniques of mitral valve replacement (MVR) for pure chronic mitral regurgitation generally result in a significant reduction in left ventricular ejection fraction.1-4 Mitral valve repair (MVP)5-7 and MVR with conservation of the chordal apparatus8 appear to spare left ventricular systolic performance when measured under resting conditions. It has been postulated that MVP preserves left ventricular function by retaining the tethering effect of the chordal apparatus and moderating the increase in wall stress that occurs after relief of mitral regurgitation.5 Furthermore, reduction in end-systolic wall stress with resultant preservation of left ventricular ejection performance has recently been demonstrated in patients having MVR with chordal preservation.8 Thus, chordal preservation appears to maintain ventricular performance, at least in part as a result of reduced afterload, and this effect appears to occur regardless of whether the valve is excised.8 Whether improved ventricular performance also occurs during exercise and translates into an improvement in functional capacity has not been investigated. Accordingly, the purpose of this study was to directly compare age-, sex-, and left ventricular performance–matched patients undergoing MVP and MVR with chordal transection to determine whether the previously documented changes in resting left ventricular wall stress and ejection performance are maintained during exercise and are correlated with exercise capacity.

Methods

Patients Between March 1989 and December 1992, 16 patients underwent MVP for chronic (≥6 months), isolated mitral regurgitation at the Medical Center Hospital of Vermont. Six patients were excluded from the study because of technically inadequate echocardiographic windows (n=2), subsequent MVR (n=1), severe postoperative mitral regurgitation (n=2), or refusal to sign informed consent (n=1). During the same time period, 87 patients underwent MVR with leaflet excision. Twenty-nine of these patients had MVR for chronic (≥6 months), isolated mitral regurgitation. For each MVP patient, a control patient was selected from the MVR group who was matched as closely as possible for age, sex, preoperative left ventricular ejection fraction, and interval from the time of surgery to participation in the present investigation. Ejection fraction was calculated angiographically9 or with quantitative echocardiography.10,11 In patients with technically adequate preoperative echocardiograms (n=17), left ventricular end-systolic and end-diastolic volumes were quantitatively measured10,11 and indexed to body surface area. Three patients (two MVP and one MVR) had technically inadequate preoperative echocardiograms for quantitative assessment and ventriculograms performed without correction for image magnification. Thus, left ventricular volumes could not be measured in these patients. Severe (4+/4+) mitral regurgitation

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From the Cardiology Unit, Medical Center Hospital of Vermont, and University of Vermont College of Medicine, Burlington, VT.

Correspondence to Marc D. Tischler, MD, Director, Cardiac Ultrasound Laboratory, Medical Center Hospital of Vermont, McClure 1, Burlington, VT 05401.
The decision to perform MVP rather than MVR was made by the referring cardiologist and cardiothoracic surgeon based on the anatomic appearance of the valve. MVP was performed on patients with posterior leaflet mitral valve prolapse and adequate tissue for valve reconstruction. MVR was performed because of severe, diffuse myxomatous degeneration involving the anterior and posterior mitral valve leaflets (n=6), disruption of the anterior leaflet (n=2), inadequate tissue for valve reconstruction (n=1), and patient request for valve replacement (n=1).

### Surgery

MVP was performed by median sternotomy and included a combination of Carpentier techniques deemed necessary at the time of surgery, as well as a rigid Carpentier annuloplasty ring.

MVR was performed by median sternotomy with excision of the mitral leaflets. The average time on bypass was 129±23 minutes for MVP compared with 113±18 minutes for MVR (P=NS). Cross-clamp time was 80±9 minutes in the MVP group compared with 68±12 minutes in the MVR group (P<.05). Three porcine valves and seven St Jude prosthetic valves were inserted.

Intraoperative transesophageal echocardiography in the 10 MVP patients revealed no residual mitral regurgitation in six patients and trivial mitral regurgitation in four patients. Transesophageal echocardiography was not routinely performed in MVR patients. After surgery, no patient had ECG or enzymatic evidence of perioperative myocardial infarction.

### Exercise Echocardiography

Resting two-dimensional echocardiographic examinations were performed with the patient supine in the left lateral decubitus position and again while sitting stationary on an upright bicycle with a phased-array ultrasonographic device (Acuson XP-5) using a 2.5-MHz transducer. Images were obtained in sequential fashion from the parasternal long-axis, parasternal short-axis, apical four-chamber, and apical two-chamber views. To minimize foreshortening of the left ventricular cavity, the transducer was held slightly lateral to the apical impulse to maximize the tomographic plane of the left ventricle. The transducer then was angulated anteriorly and posteriorly in small degrees to record the greatest long-axis length. Blood pressure was measured with a cuff sphygmomanometer at the time of the baseline echocardiographic examination. Patients then performed symptom-limited, graded upright bicycle ergometry beginning at a workload of 25 W, with 25-W increments in workload every 3 minutes. Continuous 12-lead ECG monitoring was used. Blood pressure was measured at rest and every 2 minutes during exercise. Continuous two-dimensional echocardiographic examinations were performed during exercise. Images were digitally acquired at rest and immediately after peak exercise.

### Data Analysis

All echocardiograms were evaluated by a single experienced echocardiographer (M.T.) blinded to the clinical and ECG responses to exercise and all other clinical information. With a Microsonics Image-Vue Workstation (Nova Microsonics Inc, Mahwah, NJ), three to five cardiac cycles were digitized at end systole (time of smallest cavity area) and end diastole (R-wave peak). End-systolic, end-diastolic, and stroke volumes and ejection fraction were calculated as previously described.10,11 Left ventricular volumes were calculated by the short-axis area x length method:

\[
\text{LVEDV} = \frac{\pi}{4} \times A_{ad} \times L_{ad}
\]

\[
\text{LVESV} = \frac{\pi}{4} \times A_{ad} \times L_{ad}
\]

where

- $A_{ad}$ is the area
- $L_{ad}$ is the length

\[
\text{EF} = \frac{\text{LVEDV} - \text{LVESV}}{\text{LVEDV}}
\]

### Table 1: Baseline Clinical Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mitral Valve Repair</th>
<th>Mitral Valve Replacement</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>58±14</td>
<td>59±10</td>
<td></td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>6/4</td>
<td>6/4</td>
<td></td>
</tr>
<tr>
<td>Preoperative ejection fraction, %</td>
<td>61±10</td>
<td>58±14</td>
<td></td>
</tr>
<tr>
<td>NYHA functional class, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>9</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>81±14</td>
<td>86±20</td>
<td></td>
</tr>
<tr>
<td>Sinus rhythm, n (%)</td>
<td>8 (80)</td>
<td>6 (60)</td>
<td></td>
</tr>
<tr>
<td>Atrial fibrillation, n (%)</td>
<td>2 (20)</td>
<td>4 (40)</td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>129±20</td>
<td>127±17</td>
<td></td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>87±9</td>
<td>80±13</td>
<td></td>
</tr>
</tbody>
</table>

| Medications, no.                |                     |                          |     |
| ACE inhibitor                   | 1                   | 3                        |     |
| Diuretics                       | 2                   | 5                        |     |
| Digoxin                         | 5                   | 6                        |     |
| Vasodilators                    | 0                   | 2                        |     |
| &-Blocker                       | 1                   | 0                        |     |
| Nitrates                        | 0                   | 0                        |     |

NYHA indicates New York Heart Association; bpm, beats per minute; and ACE, angiotensin-converting enzyme.

was documented in all patients by cardiac catheterization and/or Doppler echocardiography. Exclusion criteria included the presence of significant coronary artery disease at the time of coronary angiography, aortic valve disease, mitral stenosis, and, again, poor echocardiographic windows. All patients gave informed consent.

Table 1 demonstrates that the two groups of patients were well matched for age (58±14 versus 59±10 years; P=NS), sex (six men and four women in each group), interval from time of surgery to testing (19±14 versus 16±12 months; P=NS), preoperative left ventricular ejection fraction (61±10% versus 58±14%; P=NS), and other clinical variables. Left ventricular end-systolic and end-diastolic volumes were comparable in MVP and MVR patients in whom quantitative measurement was possible (Table 2). This was also true when volumes were indexed to body surface area.

### Table 2: Preoperative Left Ventricular Volumes (n=17) and Ejection Fraction (n=20)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mitral Valve Repair</th>
<th>Mitral Valve Replacement</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESV, mL</td>
<td>80±35</td>
<td>81±39</td>
<td>NS</td>
</tr>
<tr>
<td>ESVi, mL/m²</td>
<td>45±18</td>
<td>42±17</td>
<td>NS</td>
</tr>
<tr>
<td>EDV, mL</td>
<td>200±60</td>
<td>187±54</td>
<td>NS</td>
</tr>
<tr>
<td>EDVi, mL/m²</td>
<td>112±27</td>
<td>100±21</td>
<td>NS</td>
</tr>
<tr>
<td>EF, %</td>
<td>61±10</td>
<td>58±14</td>
<td>NS</td>
</tr>
</tbody>
</table>

EDV indicates left ventricular end-diastolic volume; EDVi, left ventricular end-diastolic volume index; EF, left ventricular ejection fraction; ESV, left ventricular end-systolic volume; ESVi, left ventricular end-systolic volume index; and NS, not significant.

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where LVESV and LVEDV are left ventricular end-systolic and end-diastolic volumes, $A_n$ and $A_d$ are end-systolic and end-diastolic cavity areas in which the papillary muscles are regarded as part of the left ventricular cavity, and $L_n$ and $L_d$ are left ventricular end-systolic and end-diastolic lengths, respectively. An eccentricity index was defined as the left ventricular long-axis length/left ventricular short-axis diameter $^{12,13}$ and was determined at both end systole and end diastole. An index of left ventricular end-systolic circumferential wall stress was calculated using a formula proposed by Mirkv

$$\sigma_e (\text{kdynes/cm}^2) = 1.33 P \times (A_n^{1/2} - A_d^{1/2})$$

$$\times \left[ \frac{A_n^{3/2}}{\pi (0.5L_n)^3} \times (A_n^{1/2} + A_d^{1/2}) \right]$$

where 1.33 is a constant used to convert mm Hg to kdynes/cm². $A_n$ is the total left ventricular short-axis area enclosed by the left ventricular epicardium and the right side of the septum at the level of the papillary muscles, $A_d$ is the end-diastolic cavity area in which the papillary muscles are regarded as part of the left ventricular wall, and $P$ is peak left ventricular pressure (in mm Hg). Peak left ventricular pressure was estimated from the systolic cuff blood pressure. This method, using peak systolic cuff blood pressure, has been demonstrated to correlate extremely well with estimates of wall stress based on high-fidelity end-systolic pressure measurements. $^{15}$

Statistical Analysis

All data are presented as mean±SD values. In the initial data analysis, associations between the various two-dimensional echocardiographic variables at rest and during exercise were examined using the Pearson product-moment correlation coefficient (Table 3). In addition, differences between the 10 patients with MVP (group 1) and the 10 with MVR (group 2) were assessed using a two-tailed paired Student’s $t$ test. Differences were considered significant if the null hypothesis could be rejected at $P<.05$.

Results

Baseline Clinical Data

Patients were well matched for all clinical variables. Table 1 demonstrates that there were no significant differences in the baseline demographics, functional class, heart rate, and blood pressure in patients with MVP as opposed to MVR at the time of testing. Table 2 demonstrates that preoperative left ventricular volumes and ejection fraction were comparable between the two groups, both in absolute measurements and when indexed to body surface area.

Clinical Response to Exercise

The MVP patients exercised for 11.5±6.9 minutes, stopping because of fatigue (n=8), dyspnea (n=1), or both (n=1). No patient developed chest pain or ECG evidence of ischemia. MVR patients exercised for 11.0±4.1 minutes (P=NS), also stopping because of fatigue (n=7), dyspnea (n=2), or both (n=1). Again, no patient developed chest pain or ECG evidence of ischemia. The difference in exercise duration between the two groups was not significant.

Quantitative Two-Dimensional Echocardiographic Data

The MVP group had a substantially higher stroke volume and ejection fraction (Fig 1) both at rest and during exercise in conjunction with lower end-systolic wall stress (Fig 2). The MVP group tended to have a more ellipsoidal chamber geometry at rest; this difference was even larger and statistically significant during exercise (Table 4). Furthermore, the mean change in chamber geometry from rest to exercise was qualitatively and quantitatively different in the two groups, with MVP

![Graph](http://circ.ahajournals.org/)

Fig 1. Plot of left ventricular ejection fraction (%) at rest and peak exercise in patients with MVP (o—o) and MVR (●—●).
patients becoming more ellipsoidal and MVR patients becoming more spherical ($P<.001$, Fig 3).

**Doppler Echocardiographic Data**

The mean transmitral diastolic gradient was significantly higher at rest in patients with prosthetic mitral valves ($3.4 \pm 1.0$ versus $5.1 \pm 2.0$ mm Hg; $P<.04$) and at peak exercise ($6.4 \pm 2.3$ versus $13.1 \pm 4.4$ mm Hg; $P<.002$).

**Discussion**

MVP and, more recently, MVR with chordal preservation have been shown to preserve left ventricular ejection performance at rest in patients with chronic mitral regurgitation. The present quantitative stress echocardiographic study was designed to examine whether MVP also improves left ventricular ejection performance during dynamic exercise compared with conventional MVR with chordal transection. At rest,
the MVP group had significantly greater left ventricular stroke volume and ejection fraction and lower end-systolic wall stress than the MVR group. At peak exercise, the differences in ejection fraction and wall stress became more marked, a finding that is not surprising given the high degree of correlation between rest and peak values (Table 3). In addition, the MVP group maintained a significantly more ellipsoidal chamber shape than did patients with MVR.

Previous Investigations

The technique of MVP has emerged as an important alternative to MVR in appropriate patients. Earlier investigators speculated that MVP might result in improved left ventricular function compared with conventional MVR by retaining the tethering effect of the chordal apparatus and lowering end-systolic wall stress.6,7 This hypothesis was supported by animal studies in which division of the chordae tendineae resulted in significant deterioration in left ventricular contractile force,10 an effect that can be reversed by chordal reattachment.11 Recently, Rozich et al8 compared MVR with and without chordal preservation in patients with chronic mitral regurgitation. MVR with chordal preservation resulted in smaller left ventricular size, allowing a reduced end-systolic stress and preservation of left ventricular ejection performance. These results suggest that the decrease in ejection performance after chordal transection is caused at least in part by a postoperative increase in afterload.9 Preservation of the chordae tendineae appears to result in reduced end-systolic wall stress despite removal of the low-impedance ejection pathway into the left atrium.

The importance of chamber shape has been the focus of several recent investigations. The development of a more spherical chamber shape may be detrimental to ejection performance.12 In patients with dilated cardiomyopathy, for example, a more spherical chamber is associated with more severely depressed performance at rest and a higher end-systolic wall stress.13 Chordal transection has been shown to lead to a more spherical chamber geometry at end systole in dog models.14,17,20 Rozich et al,12 in their comparison of MVR with and without chordal preservation, reported a statistically significant increase in sphericity in patients whose chordae tendineae were transected.

Preservation of a more elliptical shape may lead to improved ventricular filling. In a dog model, the generation of restoring forces that assist left ventricular filling has been shown to be closely related to eccentricity.21 At end-systolic volumes below the equilibrium volume, as occur during exercise, the ventricle develops a progressively more ellipsoidal shape as it generates more restoring forces. In animal models and human hearts, left ventricular systolic torsional motion has been postulated to represent a mechanism for storage of potential energy for restoring forces.22,23 Three-dimensional deformation of this sort is intimately related to the shape of the ventricle. Thus, an abnormality in end-systolic shape may reflect a reduced ability to generate restoring forces. Furthermore, the generation of restoring forces appears to decrease energy losses across the mitral valve.24

The present study is unique in that it examines ejection performance and wall stress both at rest and during dynamic exercise. Our results demonstrate that compared with MVR with chordal transection, MVP results in significant reductions in afterload both at rest and during exercise despite comparable heart rate—blood pressure responses. End-systolic shape tends to be more spherical at rest in patients with MVR, although this difference was not statistically significant. At peak exercise, MVP patients had significantly more spherical ventricles at end systole and a greater change in sphericity from rest to exercise. These data confirm the prior resitng study of MVR with and without chordal preservation7 and indicate that the functional advantages at rest are maintained and even potentiated during exercise. Thus, chordal preservation leads to improved left ventricular ejection fraction and stroke volume, as a result, at least in part, of reduced end-systolic wall stress, and maintenance of a more elliptical chamber geometry, which may assist left ventricular filling.

Study Limitations

Because of the relatively small sample size, it is possible that this study lacked sufficient power to detect other differences between the two patient cohorts. However, the results clearly reveal highly significant differences in rest and peak exercise end-systolic circumferential wall stress, stroke volume, and ejection fraction as well as left ventricular shape at peak exercise.

Because the effect of MVP on dynamic left ventricular performance has not previously been investigated, we elected to evaluate a number of variables. Because of these multiple comparisons, it is likely that the possibility of type I error was increased. Conventional methods of adjusting for multiple comparisons are overly conservative when the number of comparisons is more than 8 to 10.24 Although a more limited number of primary end points would have increased the significance level, the ability to comment on other associations would be sacrificed. Thus, although we cannot exclude inflation of type I error, we believe that the present analysis offers the broadest possible interpretation of the available data.

Finally, despite important differences in left ventricular ejection fraction, stroke volume, wall stress, and shape at peak exercise, the two groups exercised for comparable periods of time. Thus, the left ventricular performance differences did not have an important functional consequence in our study group. Despite controlling for preoperative ejection fraction and severity and chronicity of mitral regurgitation, there obviously are a host of other factors that influence exercise capacity but were not quantified in our study. As before, a larger sample size might have increased the power of the study sufficiently to detect differences in this particular area.

Summary

Ten patients with MVP for isolated, severe mitral regurgitation and 10 patients with conventional MVR for the same indication performed symptom-limited graded upright bicycle ergometry. The patient groups were matched for age, sex, preoperative ejection fraction, and interval from the time of surgery to testing. Quantitative echocardiographic analysis was performed...
on digitally acquired two-dimensional echocardiographic images obtained at rest and during the exercise period. MVR with chordal transection resulted in significant reductions in rest and exercise ejection fraction. This was caused in part by a significant increase in end-systolic circumferential wall stress. MVP resulted in improved rest and exercise ejection indexes, primarily due to a marked reduction in end-systolic stress and maintenance of a more ellipsoidal chamber geometry.

References
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