Reversal of left ventricular dysfunction after aortic valve replacement for chronic aortic regurgitation: influence of duration of preoperative left ventricular dysfunction

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ABSTRACT Preoperative left ventricular systolic function is an important predictor of postoperative prognosis in patients with aortic regurgitation. Although left ventricular dysfunction is reversible after aortic valve replacement to a greater extent in patients with good preoperative exercise capacity compared with patients with impaired exercise capacity, not all patients with preserved exercise capacity demonstrate improved left ventricular function after aortic valve replacement. To determine the influence of duration of preoperative left ventricular dysfunction on postoperative reversal of left ventricular dysfunction, we studied 37 patients with aortic regurgitation who preoperatively had left ventricular dysfunction, defined as subnormal echocardiographic fractional shortening (less than 29%), and good preoperative exercise capacity, defined as completion of stage I of the NIH treadmill protocol without limiting symptoms. Eight patients were asymptomatic. In 11 patients left ventricular dysfunction was documented 18 to 57 months preoperatively (prolonged); in 10 patients left ventricular dysfunction developed in an interval of 14 months or less preoperatively (brief); in 16 patients duration of left ventricular dysfunction was unknown. Patients with brief vs those with prolonged left ventricular dysfunction did not differ with respect to severity of preoperative symptoms or exercise tolerance, echocardiographically determined left ventricular dimensions or fractional shortening (25 ± 3% [SD] vs 25 ± 3%), or radionuclide angiographic ejection fraction (42 ± 5% vs 42 ± 5%). After operation, however, patients with brief left ventricular dysfunction developed a smaller left ventricular diastolic dimension (50 ± 3 vs 59 ± 8 mm; p < .005) and a higher ejection fraction (63 ± 7% vs 43 ± 12%; p < .001) than patients with prolonged left ventricular dysfunction; postoperative ejection fraction was intermediate in patients with unknown duration of preoperative left ventricular dysfunction (48 ± 11%; p < .001). All deaths occurred in patients with either prolonged or unknown duration of left ventricular dysfunction. Thus the duration of preoperative left ventricular dysfunction in patients with aortic regurgitation is an important determinant of the reversibility of left ventricular dysfunction after aortic valve replacement.

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IN PATIENTS with chronic aortic regurgitation, preoperative left ventricular contractile function is an important determinant of postoperative prognosis. Patients with impaired left ventricular systolic function are at risk of irreversible myocardial dysfunction and subsequent death from congestive heart failure despite technically successful valve replacement.1–8 However, several studies indicate that preoperative left ventricular dysfunction may be reversible in many patients after operation.9–17 A major predictor of postoperative results in such patients is the severity of preoperative symptoms, measured either subjectively by functional class6–7 or objectively by exercise tolerance13; patients with preserved exercise capacity despite left ventricular dysfunction have improved late postoperative survival and a greater likelihood of improvement in left ventricular function than patients with poor exercise capacity.13 However, although most patients in our experience with left ventricular dysfunction and preserved exercise capacity manifest an improvement in left ventricular function after operation, we have observed several such patients in whom left ventricular function has not changed or has decreased after operation. This led us to suspect that additional factors

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besides severity of preoperative symptoms might be determinants of reversibility of left ventricular dysfunction. In this study we investigated the influence of the duration of preoperative left ventricular dysfunction on the functional results of aortic valve replacement.

Methods

Patient selection. Between August 1976 and August 1983, 92 consecutive patients with chronic aortic regurgitation underwent isolated aortic valve replacement at our institution. From these 92 patients we selected 37 consecutive patients who fulfilled the following criteria: all manifested severe chronic aortic regurgitation (3+ to 4+ out of a maximum of 4+ valvular regurgitation visualized by aortic root cineangiography), preserved exercise capacity (defined as completion of the 22.5 min of the first stage of the NIH exercise protocol without symptoms), and left ventricular dysfunction (defined by echocardiographically determined left ventricular fractional shortening less than 29%). At the time of operation the patients ranged in age from 20 to 65 years (mean 41). There were 33 men and four women. Twenty-six patients underwent aortic valve replacement because of recent onset of moderate-to-severe cardiac symptoms. The other 11 patients were either asymptomatic or mildly symptomatic, and valve replacement was recommended because of consistent evidence of left ventricular dysfunction, based on serial echocardiograms and radionuclide angiograms. Eight of these patients were completely asymptomatic. All patients were evaluated preoperatively by echocardiography, radionuclide angiography, graded treadmill exercise testing, and cardiac catheterization, and all underwent isolated aortic valve replacement. All preoperative studies were performed while patients were taking no cardiac medications.

Cardiac catheterization was performed in all patients; coronary arteriography was performed in all patients over 35 years of age as well as in all patients under 35 with angina pectoris. Catheterization data confirmed isolated severe aortic regurgitation in 31 patients. Three patients had associated small ventricular septal defects with left-to-right shunt ratios less than 1.5:1. Three patients had coexistent coronary artery disease (greater than 50% reduction in luminal diameter), but only one of these had greater than 75% reduction in luminal diameter, involving one coronary artery. No patient had Marfan’s syndrome or associated disease of the ascending aorta.

Patient stratification. The patients were divided into three subgroups on the basis of duration of preoperative left ventricular dysfunction (figure 1). In 11 patients the duration of left ventricular dysfunction was prolonged, documented in 10 patients by subnormal fractional shortening on previous echocardiographic studies (when all were asymptomatic) performed 18 to 57 months (mean 34 ± 12) before operation, and in one patient (who did not have echocardiograms satisfactory for interpretation) by four serial radionuclide angiographic studies performed 1 to 39 months before operation demonstrating subnormal left ventricular ejection fraction at rest (41% to 44%). In 10 other patients the duration of preoperative left ventricular dysfunction was brief, with previous echocardiographic studies performed 1.5 to 14 months before operation (mean 8.7) demonstrating normal left ventricular fractional shortening when all were asymptomatic; the onset of left ventricular dysfunction occurred within this period. In the remaining 16 patients the duration of preoperative left ventricular dysfunction was unknown, since impaired left ventricular function was evident, and operation recommended, at the time of the initial evaluation. The symptomatic status of patients within each subgroup at the time of operation is indicated in figure 1.

Preoperative echocardiographic data are shown in figure 2 for the two subgroups of patients in whom serial preoperative data were available. In the patients with prolonged left ventricular dysfunction, early echocardiographic studies (mean 34 months before operation) performed at a time when all patients were asymptomatic demonstrated depressed left ventricular fractional shortening in every patient, ranging from 24% to 28% (mean 27 ± 1%). All patients had consistent subnormal fractional shortening on at least three preoperative echocardiograms. Fractional shortening did not change significantly in these patients by the time of the immediate preoperative study (25 ± 3%), when all but three patients had developed symptoms. In the 10 patients with preoperative left ventricular dysfunction of brief duration, an early echocardiogram performed within 14 months of operation (mean 8.7) when all patients were asymptomatic demonstrated normal left ventricular fractional shortening.

![FIGURE 1. Patients with aortic regurgitation (AR), left ventricular (LV) dysfunction (subnormal fractional shortening), and preserved exercise tolerance, subgrouped on the basis of duration of preoperative left ventricular dysfunction. LVFS = left ventricular fractional shortening.](http://circ.ahajournals.org/)
Echocardiography. M mode echocardiograms were obtained with a 2.25 mHz, 1.25 cm diameter unfocused Aerotech transducer and an Ekoline 20A or a Hoffrel 201 ultrasound receiver interfaced with a Honeywell 1856 strip chart recorder, or an Irex System II ultrasonic unit with a 2.25 MHz, 1.3 cm diameter transducer. Echocardiographic measurements of the left ventricular transverse dimensions were obtained with the ultrasound beam directed through the left ventricle just caudal to the tips of the mitral leaflets. The end-diastolic dimension was measured at the R wave of a simultaneously recorded electrocardiogram. The end-systolic dimension was measured at the peak of posterior wall systolic motion. Left ventricular fractional shortening was calculated as the ratio of the difference between the left ventricular diastolic dimension and systolic dimension to the left ventricular diastolic dimension. Interventricular septal thickness was measured just below the tips of the mitral leaflets, and left ventricular posterior wall thickness was measured at the level of the mitral leaflets. The left ventricular radius-to-wall thickness ratio (an index of the volume-to-mass ratio and a measure of the degree to which left ventricular muscle mass is appropriate for a given chamber volume) was computed as the left ventricular end-diastolic dimension divided by twice the posterior wall thickness. The muscle cross-sectional area, an index of left ventricular myocardial mass, was also computed: cross-sectional area = \( \pi \) (diastolic dimension/2) + wall thickness \( \pi \) (diastolic dimension/2).

Gated blood pool cardiac scintigraphy. Radionuclide cineangiography was performed with patients in the supine position at rest and during maximum symptom-limited exercise. Left ventricular ejection fraction was computed from the scintigraphic data as previously described. The lower limit of normal resting ejection fraction in our laboratory is 45%.

Exercise studies were performed with a bicycle ergometer and a restraining harness to minimize patient motion under the camera. Exercise loads were increased by 25 W increments every 2 min until the development of angina or limiting fatigue or dyspnea. Heart rate and blood pressure (by cuff sphygmomanometry) were monitored during exercise. Imaging was begun shortly after the onset of exercise, but only that portion of the data series that occurred during maximal exercise, encompassing approximately the last 2 to 2.5 min of exercise, was selected for analysis.

Graded treadmill exercise testing. Preoperative exercise capacity was evaluated by the NIH treadmill protocol. In the first stage of this protocol, the treadmill is driven at a constant speed of 2.2 mph at an inclination of 0%. Every 2.5 min the inclination is increased by 2.5% until a maximum of 22.5 min elapse. The maximum workload at this final stage is 2.2 mph at 20% incline, or approximately 8 mets. Previous studies demonstrate that symptomatic patients with aortic regurgitation who complete this stage of our exercise protocol without limiting symptoms have improved survival and greater reversal of left ventricular dysfunction after operation than patients who are unable to complete this stage because of limiting symptoms. All patients in this series were able to complete this stage satisfactorily.

Patients were then studied again within 48 hr on stage II of the exercise protocol for comparison of exercise tolerance. In this stage, the treadmill is initially driven at 1.9 mph at an inclination of 10%. Every 2.5 min the treadmill speed and inclination are increased by 0.4 mph and 2%, respectively. After 15 min the inclination is held constant at 20% and the speed is increased 0.8 mph every 2.5 min. Exercise is continued until the patient complains of angina or limiting fatigue or dyspnea.

Aortic valve replacement. At operation, 18 patients received Starr-Edward prostheses (1260 Series in 14, 2320 series...
PATHOPHYSIOLOGY AND NATURAL HISTORY—AORTIC DISEASE

in two, and 2400 series in two). 17 received Hancock porcine bioprosthesis model 242, and two received a Bjork-Shiley prosthesis. Cardiopulmonary bypass was performed with a disc or bubble oxygenator at a flow rate of 2.2 liters/min/m². Cardiopulmonary bypass times ranged from 55 to 158 min (mean 88 ± 26), and aortic cross-clamp times ranged from 35 to 97 min (mean 57 ± 16). In addition to systemic hypothermia to 30° to 31°C in all patients, myocardial preservation techniques included topical 4°C iced saline with coronary perfusion in 15 patients and hyperkalemic cold cardioplegia and topical hypothermia in 22. Myocardial preservation techniques, cardiopulmonary bypass and aortic cross-clamp times, and the type of prosthetic valve implanted were not different among the three subgroups of patients. The operative dates were also similar: four of 10 patients with brief and six of 16 patients with unknown duration of left ventricular dysfunction underwent operation after January 1980, compared with four of 10 patients with brief and six of 16 patients with unknown duration of left ventricular dysfunction.

Postoperative studies. Patients returned 4 to 8 months (mean 6) after operation for repeat cardiac catheterization, echocardiographic, and radionuclide angiographic studies. These studies were performed after patients were withdrawn from all cardiac medications, except for antiarrhythmic drugs in six patients. Left heart catheterization was performed with either the transeptal or the left ventricular puncture technique. Echocardiographic left ventricular systolic dimension and fractional shortening were not analyzed for the group because of abnormal septal motion in many patients after operation.5, 23

Postoperative hemodynamic data demonstrated peak systolic gradients across the prosthetic valve of less than 10 mm Hg in 20 patients, between 10 and 20 mm Hg in 13 patients, and greater than 20 mm Hg in three patients: 25 mm Hg in one patient in the subgroup with unknown duration of preoperative left ventricular dysfunction, 30 mm Hg in one patient with prolonged dysfunction, and 40 mm Hg in one patient with brief dysfunction. These valve gradients were associated with cardiac indexes of 2.0, 4.4, and 3.1 liters/min/m², respectively. No patient had a prosthetic valve gradient greater than 40 mm Hg. One patient with unknown duration of preoperative left ventricular dysfunction had persistent severe (4 + out of 4 + ) aortic regurgitation 7 months after operation because of a perivalvular leak, underwent a second operation 8 months after the initial valve replacement, and is now asymptomatic 19 months after repair of the perivalvular leak. For comparison with other patients, the data obtained 6 months after repair of the perivalvular leak are used in this patient.

Serial postoperative studies were obtained in a subset of patients. In 22 patients early postoperative echocardiograms were obtained 10 to 15 days after operation, when all patients were receiving digoxin. Late postoperative echocardiographic studies were performed in 18 patients, including five with prolonged and six with brief left ventricular dysfunction. This represents 86% of patients for whom 4 year postoperative data are available. These long-term studies were obtained between 46 and 82 months (mean 62) after operation. At the time of these late studies, nine patients were receiving digoxin and three were receiving propranolol.

Statistical methods. Comparisons of preoperative or postoperative data among subgroups were performed with the t test for unpaired data. Changes in echocardiographic and radionuclide angiographic data from before to after operation within subgroups were analyzed by the paired t test. Life-table curves were plotted by the Kaplan-Meier method24 and differences in survival among subgroups were analyzed by the Mantel-Haenszel method.25

Results

Preoperative data. Before operation, the three subgroups with prolonged, brief, or unknown duration of preoperative left ventricular dysfunction did not differ with respect to age, exercise capacity, or hemodynamic data (table 1). Preoperative echocardiographic left ventricular dimensions, fractional shortening, radius-to-wall thickness ratio, and muscle cross-sectional area also did not differ among subgroups, nor did radionuclide angiographic ejection fractions at rest or during exercise (table 1). Preoperative fractional shortening was subnormal in all patients (reflecting our

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**TABLE 1**

Preoperative data

<table>
<thead>
<tr>
<th>Preoperative variable</th>
<th>Duration of preoperative LV dysfunction</th>
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<tbody>
<tr>
<td></td>
<td>Prolonged (n = 11)</td>
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<tr>
<td>Age</td>
<td>39 ± 9</td>
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<tr>
<td>Exercise capacity (min)</td>
<td>13 ± 3</td>
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**Hemodynamic data**

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<tr>
<td>LV peak systolic pressure (mm Hg)</td>
<td>143 ± 27</td>
<td>146 ± 20</td>
<td>134 ± 22</td>
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<tr>
<td>LV end-diastolic pressure (mm Hg)</td>
<td>13 ± 7</td>
<td>14 ± 8</td>
<td>16 ± 8</td>
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<td>Pulmonary wedge pressure (mm Hg)</td>
<td>13 ± 7</td>
<td>11 ± 4</td>
<td>14 ± 5</td>
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<tr>
<td>Cardiac index (liters/min/m²)</td>
<td>2.9 ± 0.7</td>
<td>2.6 ± 0.7</td>
<td>2.8 ± 0.7</td>
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**Echocardiographic data**

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<th>Prolonged</th>
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<tbody>
<tr>
<td>LV end-diastolic dimension (mm)</td>
<td>76 ± 8</td>
<td>75 ± 6</td>
<td>76 ± 6</td>
</tr>
<tr>
<td>LV end-systolic dimension (mm)</td>
<td>57 ± 6</td>
<td>56 ± 5</td>
<td>58 ± 6</td>
</tr>
<tr>
<td>LV fractional shortening (%)</td>
<td>25 ± 3</td>
<td>25 ± 3</td>
<td>24 ± 4</td>
</tr>
<tr>
<td>LV radius-to-wall thickness ratio</td>
<td>3.2 ± 0.6</td>
<td>3.3 ± 0.8</td>
<td>3.3 ± 0.6</td>
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<td>LV muscle cross-sectional area (cm²)</td>
<td>38 ± 12</td>
<td>37 ± 6</td>
<td>36 ± 6</td>
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**Radionuclide angiographic data**

<table>
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<th>Prolonged</th>
<th>Brief</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV EF at rest (%)</td>
<td>42 ± 5</td>
<td>42 ± 5</td>
<td>39 ± 5</td>
</tr>
<tr>
<td>LV EF during exercise (%)</td>
<td>36 ± 9</td>
<td>33 ± 11</td>
<td>30 ± 5</td>
</tr>
<tr>
<td>LV EF response to exercise (%)</td>
<td>−7 ± 6</td>
<td>−9 ± 10</td>
<td>−8 ± 3</td>
</tr>
</tbody>
</table>

Data are mean ± SD.

EF = ejection fraction; LV = left ventricular.

An = No variable was significantly different among the three subgroups.

BDuration of exercise on stage II of NIH treadmill protocol.

C Ratio = (LV diastolic dimension)/(2 × LV posterior wall thickness).

DSee Methods for definition.

ELV EF response to exercise = exercise LV EF minus resting LV EF.

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patient selection criteria), and radionuclide angiographic ejection fraction was at the lower limit of normal (45%) or less in 30 patients. In the other seven patients (four with prolonged, two with brief, and one with unknown duration of left ventricular dysfunction), ejection fraction ranged from 46% to 49%, within the reproducibility error of the lower limit of normal by our technique.²⁶

**Clinical course after aortic valve replacement.** None of the 37 patients died at operation. Two patients with normal coronary arteries developed electrocardiographic changes immediately after operation compatible with an intraoperative myocardial infarction. One of these patients died 35 days after operation from low cardiac output, representing the only early postoperative death in this series. This patient had the lowest preoperative ejection fraction at rest (26%) and fractional shortening (15%) of all patients in this series, associated with left ventricular dimensions of 72 mm at end-diastole and 61 mm at end-systole. All remaining 36 patients returned for postoperative hemodynamic and noninvasive studies 6 months after valve replacement.

Four patients died after the 6 month postoperative evaluation from congestive heart failure, 10, 36, 54, and 64 months after valve replacement. Three of the four patients complained of persistent symptoms of pulmonary congestion at the time of the 6 month postoperative study, and two had overt evidence of left ventricular failure. The fourth patient died 36 months after operation from left ventricular failure because of dysfunction of a porcine heterograft valve despite normal hemodynamic function of this valve at the 6 month evaluation. Two patients have been lost to follow-up but were known to be alive with no cardiac symptoms 24 and 30 months after operation. The remaining 30 patients are alive with a mean postoperative follow-up period of 51 months. The duration of postoperative follow-up was similar among three subgroups of patients (table 2).

**Postoperative data.** Six month postoperative hemodynamic and noninvasive data for the three subgroups of patients are presented in table 2. Left ventricular end-diastolic pressure, cardiac index, and prosthetic aortic valve gradient did not differ significantly among the three subgroups. Muscle cross-sectional area was not significantly different after operation among the three subgroups (table 2). However, postoperative cross-sectional area was not significantly different compared with preoperative values in the group with prolonged dysfunction, whereas it decreased significantly in the subgroup in which the duration of left ventricular dysfunction was either brief (37 ± 6 to 28 ± 4 cm²; p < .001) or unknown (36 ± 6 to 28 ± 5 cm²; p < .005). The echocardiographic left ventricular end-diastolic dimension, which decreased after operation in each

**TABLE 2**

<table>
<thead>
<tr>
<th>Postoperative variable</th>
<th>Duration of preoperative LV dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prolonged (n = 11)</td>
</tr>
<tr>
<td>Postoperative follow-up period (mo)</td>
<td>51 ± 12 NS</td>
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<tr>
<td>Hemodynamic data</td>
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<tr>
<td>LV end-diastolic pressure (mm Hg)</td>
<td>9 ± 3 NS</td>
</tr>
<tr>
<td>Cardiac index (liters/min/m²)</td>
<td>3.0 ± 0.7 NS</td>
</tr>
<tr>
<td>Prosthetic valve gradient (mm Hg)</td>
<td>7 ± 10 NS</td>
</tr>
<tr>
<td>Echocardiographic data</td>
<td></td>
</tr>
<tr>
<td>Muscle cross-sectional area (cm²)</td>
<td>33 ± 14 NS</td>
</tr>
<tr>
<td>Change in muscle cross-section area (cm²)</td>
<td>-5 ± 9 NS</td>
</tr>
<tr>
<td>LV end-diastolic dimension (mm)</td>
<td>59 ± 8 &lt;.005</td>
</tr>
<tr>
<td>Change in LV end-diastolic dimension (mm)</td>
<td>-16 ± 8 &lt;.02</td>
</tr>
<tr>
<td>Radionuclide angiographic data</td>
<td></td>
</tr>
<tr>
<td>LV EF at rest (%)</td>
<td>43 ± 12 &lt;.001</td>
</tr>
<tr>
<td>Change in LV EF at rest (%)</td>
<td>1 ± 10 &lt;.001</td>
</tr>
<tr>
<td>LV EF during exercise (%)</td>
<td>43 ± 13 &lt;.001</td>
</tr>
<tr>
<td>Change in LV EF during exercise (%)</td>
<td>7 ± 9 &lt;.001</td>
</tr>
</tbody>
</table>

Data are mean ± SD.
See table 1 for abbreviations.
AComparison of brief vs prolonged subgroups.
BComparison of brief vs unknown duration subgroups.
CCompared to preoperative value.
ventricular dysfunction manifested a higher postoperative left ventricular ejection fraction at rest and a greater change compared with the preoperative value than patients with either prolonged or unknown duration of preoperative left ventricular dysfunction (table 2, figure 4). This observation was also true for postoperative changes in the left ventricular ejection fraction during supine exercise (figure 5).

One patient in the subgroup with prolonged left ventricular dysfunction, with electrocardiographic evidence of an intraoperative myocardial infarction, manifested a decrease in ejection fraction after operation compared with the preoperative value (from 40% to 21% at rest), associated with the highest postoperative left ventricular end-diastolic dimension of all patients (figures 3 and 4). This patient subsequently died 64 months after operation. When this patient’s data were excluded from analysis, the postoperative trends in patients with prolonged duration of left ventricular dysfunction were unchanged, with higher postoperative left ventricular end-diastolic dimensions (58 ± 8 mm; p < .005) and lower ejection fractions both at rest (45 ± 10%; p < .001) and during exercise (45 ± 11%; p < .001) compared with patients with brief left ventricular dysfunction.

To investigate the influence of myocardial preservation techniques on these functional results of aortic valve replacement, the postoperative analysis was re-

subgroup, was significantly lower after operation in patients in whom preoperative left ventricular dysfunction was brief compared with patients with either prolonged or unknown duration of preoperative left ventricular dysfunction (table 2, figure 3). Postoperative end-diastolic dimension was normal (55 mm or less) in all patients in the subgroup with brief preoperative left ventricular dysfunction compared with two of 10 patients with prolonged left ventricular dysfunction and six of 15 patients with unknown duration of left ventricular dysfunction.

Similar trends were observed in the postoperative radionuclide angiographic data. Left ventricular ejection fraction at rest significantly increased after operation for the entire patient population considered together (from 41 ± 5% to 50 ± 3%; p < .001), but the extent to which ejection fraction improved varied among subgroups. Patients with brief preoperative left

FIGURE 3. Change in echocardiographic left ventricular (LV) end-diastolic dimension from before (preop) to 6 months after (postop) operation in the three subgroups of patients. Open symbols, patients with no preoperative symptoms; asterisks, three patients who subsequently died with symptoms of congestive heart failure; cross, one patient who subsequently died from prosthetic valve dysfunction; slashed circles, mean values. The dashed line at 55 mm indicates the upper limit of normal for end-diastolic dimension.
peated separately in the 15 patients receiving coronary perfusion and topical hypothermia and the 21 patients receiving cold hyperkalemic cardioplegia and topical hypothermia. Postoperative end-diastolic dimensions and ejection fractions were not different between these two subgroups. Moreover, within each of these two subgroups, patients with brief preoperative left ventricular dysfunction manifested smaller diastolic dimensions and greater ejection fractions after operation (figure 6) than patients with prolonged left ventricular dysfunction. The improvement in left ventricular function after operation was also not influenced significantly by the type or size of the prosthetic valve implanted, the cardiopulmonary bypass or aortic cross-clamp time, or the postoperative prosthetic valve gradient.

By life-table analysis, the 3 year postoperative survival in the entire population was 92 ± 5%. It was 100% in the subgroup with brief left ventricular dysfunction, 87 ± 9% in the subgroup with unknown duration of left ventricular dysfunction, and 91 ± 9% in the subgroup with prolonged left ventricular dysfunction. Despite these trends, the differences in survival were not statistically different.

**Serial postoperative data.** Early postoperative echocardiographic data obtained in 22 patients demonstrated a significant decrease in left ventricular end-diastolic dimension from before operation to 10 to 15 days after (76 ± 7 to 60 ± 7 mm; p < .001), with a further small decrease at 6 months (56 ± 8 mm; p < .02). Only seven patients manifested a decrease in diastolic dimension of greater than 5 mm (range 9 to 18) between the early postoperative and 6 month studies; two of these patients had prolonged and three had brief preoperative left ventricular dysfunction.

Late postoperative data (4 years or greater) obtained in 18 patients demonstrated no change compared with the 6 month postoperative data in end-diastolic dimension (from 53 ± 8 to 54 ± 9 mm; NS) or muscle cross-sectional area (from 31 ± 11 to 29 ± 13 cm²; NS). In the five patients in this group with prolonged preoperative dysfunction, neither variable differed between the 6 month and long-term postoperative studies (56 ± 10 vs 54 ± 15 mm and 36 ± 19 vs 35 ± 18 cm², respectively).

**FIGURE 6.** Influence of myocardial preservation techniques (coronary perfusion vs cold hyperkalemic cardioplegia) on the change in resting left ventricular (LV) ejection fraction from before to 6 months after aortic valve replacement (AVR). Asterisks and cross are defined in legend to figure 3.
Discussion

Survival and functional results after aortic valve replacement for aortic regurgitation are influenced strongly by preoperative left ventricular systolic function. Ejection phase indexes of left ventricular function, such as angiographic ejection fraction or echocardiographic fractional shortening, are helpful in predicting the results of operation and hence may be used to identify a subgroup of patients with impaired left ventricular function who are at risk of irreversible left ventricular dysfunction and death from congestive heart failure during the long-term postoperative course. However, preoperative left ventricular dysfunction is not always irreversible; numerous studies have shown that left ventricular dysfunction may often improve and even normalize after successful valve replacement. Such salutary effects may result, at least in part, from advances in myocardial preservation techniques during surgery. Three recent studies reported excellent postoperative survival in patients with aortic regurgitation regardless of the presence or absence of left ventricular dysfunction. The authors concluded that because of improved myocardial preservation techniques, preoperative left ventricular systolic function is no longer an important risk factor for postoperative congestive heart failure or death. This conclusion can be considered only inferential, however, since the results with other myocardial protection techniques were not compared and other factors, such as patient selection and timing of operative intervention, may have an important impact on the improved results of recent operative series. For example, it has been demonstrated that the subgroup of patients with left ventricular dysfunction but with minimal or no symptoms, as measured by functional class or exercise capacity, have a better prognosis after operation and a greater likelihood that left ventricular function will improve than do patients with an equal degree of left ventricular dysfunction but with more severe symptoms. This experience has reinforced the recommendation that aortic valve replacement be performed in all patients with evidence of left ventricular dysfunction before significant symptoms develop. This recommendation, in practice, should result in improved survival and functional results after aortic valvular replacement even when left ventricular dysfunction has already appeared.

Although most patients with preserved exercise capacity and left ventricular dysfunction experience an improvement in left ventricular function after operation, many do not. Several asymptomatic or minimal-symptomatic patients in our series, who on the basis of symptomatic status and exercise tolerance would be expected to have had a significant improvement in left ventricular function after operation, manifested either no change or a deterioration (figures 4 and 5). This led us to suspect that additional factors besides preoperative exercise tolerance and severity of symptoms might be determinants of the functional results of operation.

Our data suggest that the duration of time that left ventricular dysfunction has been present is a critically important factor in determining its reversibility. In this study we used subnormal echocardiographic fractional shortening to define preoperative left ventricular dysfunction. This was confirmed by radionuclide angiographic studies. In 30 patients resting ejection fraction was less than or equal to 45%, the lower limit of normal of our technique, and in the other seven patients with normal values it was within the reproducibility error of the lower limit of normal. Patients in our series who had left ventricular dysfunction at the time of operation but had normal indexes of left ventricular systolic function within 14 months before operation demonstrated significantly greater reversal of left ventricular size and contractile function than patients with an equal degree of left ventricular dysfunction in whom impaired contractile function was documented 18 months or longer before operation. Thus despite similar symptomatic status and objective exercise tolerance, as well as similar hemodynamic, echocardiographic, and radionuclide angiographic variables, the patients with brief preoperative left ventricular dysfunction experienced a greater decrease and normalization of left ventricular end-diastolic dimension after operation (figure 3). This reduction in end-diastolic dimension is important from a prognostic standpoint, since patients with persistent left ventricular dilatation after operation have been shown to be at risk of death of congestive heart failure during the long-term postoperative course. Four of seven patients with postoperative end-diastolic dimensions greater than 60 mm died during subsequent follow-up, three of congestive heart failure. These changes in diastolic dimensions were paralleled by changes in systolic function. Although ejection fraction at rest or during exercise was not different among the three subgroups of patients before operation, it was significantly higher after operation in patients whose duration of preoperative left ventricular dysfunction was brief compared with those in whom the duration of left ventricular dysfunction was either prolonged or unknown (figures 4 and 5).
These differences in postoperative functional data among the three subgroups could not be explained on the basis of differences in myocardial preservation techniques (figure 6), differences in cardiopulmonary bypass or aortic cross-clamp times, or differences in prosthetic valve type and size or postoperative pressure gradient.

Although the long-term functional evaluation at 4 years is not complete, our preliminary results suggest that no substantial improvement in left ventricular end-diastolic dimension or muscle cross-sectional area occurs after 4 to 8 months after operation. These data support previous studies demonstrating only trivial changes in end-diastolic dimension and muscle cross-sectional area after the fourth to sixth postoperative month. Hence, our data indicate that the extent of recovery of left ventricular function after operation is strongly influenced by the duration for which preoperative left ventricular dysfunction has been present.

Our study was not designed to test the efficacy of different operative techniques or different prosthetic valves in determining the outcome of operation. Although these factors undoubtedly have an important effect on the functional results of aortic valve replacement, it can be inferred from our results that the duration of preoperative left ventricular dysfunction is a more powerful determinant of reversibility of left ventricular dysfunction after operation. These data may provide an explanation for the differences in postoperative survival and postoperative reversal of left ventricular function reported from different centers for patients with aortic regurgitation and preoperative left ventricular dysfunction. Excellent results might be anticipated if patients undergo operation shortly after the onset of left ventricular dysfunction; poorer results would be anticipated for those patients with long-standing dysfunction, even in the absence of severe symptoms. Our data therefore provide further evidence that the asymptomatic or mildly symptomatic patient with left ventricular dysfunction at rest should undergo operation without delay once definite and reproducible evidence of left ventricular dysfunction is documented, since the risk of irreversible myocardial dysfunction developing would be increased if aortic valve replacement is delayed until the onset of more severe symptoms.

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