Observations on the Optimum Time for Operative Intervention for Aortic Regurgitation

I. Evaluation of the Results of Aortic Valve Replacement in Symptomatic Patients

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SUMMARY Fifty consecutive patients undergoing aortic valve replacement for isolated aortic regurgitation were studied prospectively by echocardiography, electrocardiography and cardiac catheterization. Good quality echocardiograms were obtained in 49 of the 50 patients. Left ventricular (LV) dilatation was present in all 49 patients. LV systolic function, as assessed by echocardiographic percent fractional shortening, was normal in many patients but was moderately to severely reduced (<25%) in 14 patients (29%). Echocardiographic studies 6 months postoperatively revealed significant reductions in LV end-diastolic diameter (73.8 mm vs 58.7 mm; p < 0.01), and serial echocardiographic studies early and late after operation revealed that the decrease in LV size had occurred by the time of the early study (8–22 days postoperatively), with little additional change thereafter. Operative deaths occurred in three of the 49 patients (6%). Eight of the 49 patients (16%) died of congestive heart failure (CHF) after hospital discharge at times ranging from 5–43 months after operation. Preoperative echocardiographic measurements of the LV end-systolic dimension and percent fractional shortening were strongly associated (p < 0.01) with these late CHF deaths. Preoperative LV end-systolic dimension >55 mm and fractional shortening <25% identified the high-risk group: nine of 13 patients (69%) in this group died either at operation or subsequently from CHF. In contrast, of 32 patients with LV end-systolic dimension ≤55 mm, only one died at operation and one died late from CHF. Thus, the population at high risk of late death from CHF was identified before operation by echocardiography.

MOST PATIENTS who undergo aortic valve replacement for aortic regurgitation survive operation and have sustained relief of symptoms for many years. Others survive operation but later develop progressive symptoms of congestive heart failure and die several months to years after valve replacement. It is usually assumed that irreversible left ventricular dysfunction occurred before operation in these patients and produced symptoms of congestive heart failure after operation. In this paper, we describe the results of a prospective study of patients undergoing aortic valve replacement for isolated aortic regurgitation. The study had three goals: 1) to define the echocardiographic and hemodynamic characteristics of symptomatic patients who require operation because of severe aortic regurgitation; 2) to determine the changes that occur in these echocardiographic and hemodynamic measurements after successful aortic valve replacement; and 3) to identify variables measured before operation that were associated with a high risk of dying at operation or developing symptoms of congestive heart failure and dying after operation. If factors highly associated with mortality could be identified, it might be possible to predict the result of operation in individual patients more reliably and, more important, to determine the optimum timing of operative intervention.

Methods

Patients

The patient population consisted of all patients with long-standing aortic regurgitation who had aortic valve replacement between January 1972 and June 1977. Patients were included in the study population if they had aortic regurgitation visualized by cineangiography after injection of dye into the aortic root that was severe enough to produce opacification of the left ventricle that failed to clear during the subsequent cardiac cycle. Patients were excluded if the gradient across the aortic valve exceeded 20 mm Hg, if dysfunction of other heart valves was severe enough to require valve replacement, if aortic root disease existed requiring aortic root reconstruction at the time of valve replacement, or if valvular surgery had been performed previously. All patients had severe dyspnea on exertion, overt congestive heart failure (orthopnea, paroxysmal nocturnal dyspnea, pulmonary edema),
angina pectoris or syncope. The presence of coronary artery disease or left ventricular dysfunction was not used to exclude patients from study.

Forty-nine of the 50 patients who met the selection criteria had good-quality preoperative echocardiograms and were accepted into the study. There were 40 men and nine women, ages 19–68 years (mean 46 years). Forty-one patients had either 2320 series (30 patients) or 2400 series (11 patients) Starr-Edward prosthetic valves, two had Björk-Shiley valves and six had porcine heterograft valves placed at operation. Coronary artery perfusion was used during cardiopulmonary bypass in 31 patients, coronary perfusion plus topical iced saline was used in nine patients, and topical iced saline alone was used in six patients. Three patients had neither coronary artery perfusion nor topical iced saline.

Ten of the 49 patients (20%) had coexistent coronary artery disease. Four of these 10 patients (40%) had saphenous vein bypass grafts placed at the time of aortic valve replacement. Figure 1 is a flow chart of the results and follow-up of all patients in the study. The patient who was excluded from the study because of poor-quality echocardiographic records both before and after operation is still alive.

**Patient Studies**

History, physical examination, 12-lead ECG, echocardiogram, and left- and right-heart cardiac catheterization were obtained before and 6 months (range 5–11 months) after operation. In the preoperative studies, left-heart catheterization was performed retrogradely from the aorta. Six-month postoperative studies were performed using either the transseptal or percutaneous ventricular puncture technique. Cardiac output was obtained using the indocyanine green dye technique. Digitalis and diuretics were discontinued for at least 3 days before cardiac catheterization.

Left ventricular contrast cineangiography was attempted in most patients before operation, but images satisfactory for volume analysis were available in only 23 patients. In many patients, premature ventricular depolarizations, inadequate dye concentration, hemodynamic instability or technical factors prevented the angiographic data from being useful. Preoperative ventriculograms were available in only three patients who either died at operation or during follow-up. Because of the small number of patients, the ventriculographic data could not be evaluated for their association with mortality.

Coronary artery anatomy was assessed in 47 of 49 patients by preoperative coronary cineangiography (36 patients), 6-month postoperative coronary cineangiography (eight patients) or autopsy examination (three patients).

Twelve-lead ECGs were obtained in every patient before operation and at 6-month postoperative study in all patients who returned for follow-up evaluation. Romhilt-Estes scores were computed, as previously described, for all patients, including the three patients with complete left bundle branch block.

Echocardiograms were performed in all 49 patients before operation, and 6 months after operation in 39 patients. Echocardiographic studies were performed in 26 patients 8–22 days (mean 11 days) after operation ("early" postoperative studies). In 16 patients, studies were performed "late" (21–63 months, mean 34 months) after operation. It is not clear whether any important selection factors determined what patients had early or late postoperative echocardiographic studies. However, comparison of the preoperative echocardiographic data from these patients with the preoperative data from the rest of the patient population failed to reveal any significant differences (p > 0.05).

Echocardiograms were obtained using either an Ekoline 20A or a Hoffrel 201 ultrasound transceiver interfaced to a Honeywell 1856 strip-chart recorder. A 1.25-cm diameter, 2.25-MHz unfocused ultrasound transducer was used; a switched-gain circuit was used to simplify measurement of left ventricular posterior
free wall thickness. Echocardiographic measurements included heart rate, left ventricular transverse dimensions at end-diastole and end-systole, and ventricular septal and left ventricular free wall thicknesses. These measurements were made using the T-scan technique, with the ultrasound beam passing through the left ventricle just caudal to the tips of the mitral leaflets. From these primary measurements, percent fractional shortening of the left ventricle was calculated as the ratio of the difference between the left ventricular diastolic and systolic dimensions to the left ventricular diastolic dimension. Left ventricular ejection fraction and mass were estimated using the cubed assumption. Aortic root and left atrial dimensions were measured in all patients before operation, but not after operation, because the presence of the prosthetic valve made it difficult to identify the posterior wall of the aorta. In two patients, the aortic root dimension slightly above the aortic leaflets was significantly greater than that at the level of the aortic valve. In these two patients, the larger measurement was used.

Mortality Analysis

The association between the several patient variables and overall mortality was tested by Cox's method of life-table analysis. The total survival experience of the 49 patients was studied using the preoperative findings as the independent variable and death from any cause as the end point. The survival experience beginning 30 days after operation was also analyzed using preoperative measurements, with death related to congestive heart failure as the end point. Death was assumed to be related to congestive heart failure if patients died after experiencing postoperative symptoms of severe dyspnea on exertion, orthopnea, paroxysmal nocturnal dyspnea, or pulmonary edema. The mortality experience of the patients who survived operation and returned for repeat study 6 months after operation was also analyzed separately using measurements from the 6-month follow-up study as independent variables and subsequent death from congestive heart failure as the end point.

Results

Patient Follow-up

Three in-hospital deaths occurred among the 49 patients (fig. 1); none of the three patients who died at operation had coronary artery disease. Forty-six patients survived operation and were discharged from the hospital. Eight patients with symptoms of congestive heart failure died 5–42 months after operation; two of these patients died before the 6-month postoperative study. The mean age of the eight patients who died late of congestive heart failure was 47.6 years (range 28–66 years), which did not differ from the mean age (47.2 years) of the other 41 patients. These eight patients could not be distinguished from the other patients based on sex, duration of symptoms, preoperative digitalis therapy, type of prosthetic valve or type of myocardial preservation. Only one of the eight patients (13%) who died late due to congestive heart failure had coronary artery disease.

Three patients without symptoms of congestive heart failure died 23, 42 and 46 months after operation. Two of these three deaths were related to complications of coronary artery disease (see below). The third patient, who did not have coronary artery disease, died while swimming; we do not know whether this represented sudden cardiac death or drowning. If all the patients with follow-up information of any kind are included, 32 are alive, with a mean follow-up of 44 months. Thirty patients with postoperative echocardiograms are still alive, with a mean follow-up of 42 months. The overall mortality was 14 of 49 patients (29%). Operative mortality was three of 49 patients (6%). Late mortality due to any cardiac cause (including the death while swimming) was 11 of 46 patients (24%), giving an average annual late mortality of 7% per year.

Of the 10 patients with coronary artery disease, six did not have saphenous vein bypass grafts at valve replacement. Three of these six patients subsequently had acute myocardial infarctions (one of the three died), and one patient developed severe angina several months after valve replacement. This patient died during a coronary artery bypass operation performed at another institution. No coronary-related events have occurred in the four patients who had saphenous vein grafts placed at valve replacement. Only two of the 10 patients with coronary artery disease had fractional shortening less than 25% preoperatively, and one of these patients was the only patient of the 10 that developed congestive heart failure and died during long-term follow-up after operation.

Preoperative Evaluation

The preoperative echocardiographic measurements obtained in the 49 patients with satisfactory echocardiograms are shown in figures 2 and 3. Figure 2 gives direct echocardiographic measurements and the calculated left ventricular fractional shortening. The data in figure 3 are expressed as a percentage of the expected value corrected for age and body surface area obtained using regression equations derived from a large series of younger and older normal subjects. Left ventricular fractional shortening is independent of body surface area; the normal range for our laboratory is given in figure 2. The internal dimensions of the left ventricle at end-diastole and at end-systole were increased in nearly every patient, often markedly. The thicknesses of the left ventricular free wall and the ventricular septum were increased in 38 of 49 patients (78%). The ratio of ventricular septal thickness divided by left ventricular free wall thickness ranged from 0.77–1.9 (mean ± SEM 0.96 ± 0.01). Estimated left ventricular mass was increased above the normal range in every patient. Fractional shortening of the left ventricle was below the normal range in 28 of 49 patients (57%); in 14 of 49 patients (29%), fractional shortening was less than 25%. The results were similar when estimated ejection fraction...
The horizontal line the 2.

**FIGURE 2. Preoperative echocardiographic measurements.** The mean value is indicated by the open symbol with the horizontal line at the extreme right of each column. Left ventricular fractional shortening in percent is shown on the right; the stippled area represents the normal range. LVD (DIA) = left ventricular dimension at end-diastole; LVD (SYS) = left ventricular dimension at end-systole; Ao = aortic root dimension; LA = left atrial dimension; LVPW = left ventricular posterior wall.

was used. The aortic root and left atrial dimensions were both significantly increased (p < 0.01).

**Six-month Postoperative Evaluation**

Forty-one of the 49 patients underwent hemodynamic evaluation 6 months after operation. Postoperative pressure gradient measurements across the prosthetic aortic valve were less than 30 mm Hg in all but five patients. One of the five patients had a gradient of 60 mm Hg and a perivalvular leak. This patient is alive and well after a second aortic valve replacement. The other four patients, all with prosthetic valve gradients of 35–45 mm Hg, are alive and well. Postoperative valve areas were not computed because of the small mean valvular gradient (14 mm Hg). The hemodynamic data before and after operation, as well as Romhilt-Estes scores, are summarized in table 1.

Thirty-nine patients had both preoperative and 6-month postoperative echocardiographic studies (table 1 and fig. 4). The mean left ventricular dimensions at end-diastole decreased significantly (p < 0.01) after operation. Mean ventricular septal and left ventricular posterior wall thicknesses, however, were unchanged (p > 0.05). Because of the marked decrease in the mean internal dimension of the left ventricle, the mean estimated left ventricular mass decreased markedly after operation (p < 0.01).

**Operative Deaths or Perioperative Myocardial Damage**

Three patients died of low cardiac output early after operation. Six other patients who survived operation and were discharged from the hospital had evidence of operative myocardial damage. Three had postoperative ECGs indicating a new transmural myocardial infarction and three had areas of ventricular dyskinesis involving regions other than the apical vent site at cineangiography 6 months postoperatively. Only one of these nine patients had coronary artery disease. However, five of the nine had a left ventricular end-systolic dimension at preoperative echocardiographic study that was greater than 55 mm and a fractional shortening that was less than 25%.

When all thirteen patients who had both a left ventricular end-systolic dimension greater than 55 mm and a fractional shortening less than 25% are considered, five of 13 (38%) either died early after opera-

**FIGURE 3. Preoperative echocardiographic measurements in the 49 patients expressed as a percentage of the expected value (expected value computed from the patient's age and body surface area using previously derived regression equations).** The 95% confidence limit for normal data is indicated by the stippled area. The p value indicates whether the mean value is significantly different from normal. See legend to figure 2 for symbols and abbreviations. The mean value is indicated by the open symbol with the horizontal line at the extreme left of each column.
tion or had evidence of operative damage. In contrast, operative death or damage occurred in four of 36 patients (11%) who had either a left ventricular end-diastolic dimension less than or equal to 55 mm or a fractional shortening equal to or greater than 25%. This difference is statistically significant (p < 0.05) by Fisher's exact test.21

Serial Echocardiographic Evaluation

Twenty-six patients had both preoperative and early postoperative echocardiograms. Three of these 26 patients had evidence of intraoperative myocardial damage by ECG changes (one patient) or new ventricular dyskinesia on contrast cineangiography (two patients). Two other patients who were studied early postoperatively died before discharge from the hospital after operation. These five patients had a decrease in the left ventricular end-diastolic dimension at the early postoperative study of only 6 mm or less. All of the remaining 21 patients had at least an 11-mm decrease in the end-diastolic dimension at the early postoperative study. The preoperative and early postoperative paired echocardiographic data for these 21 patients are summarized in table 2. Paired measurements obtained at study early and 6 months postoperatively in 20 patients are also summarized in table 2.

Left ventricular diastolic dimensions had decreased significantly at the early postoperative study and did not change further between the early study and the 6-month postoperative study. Heart rate was increased at the early postoperative study, but decreased to the preoperative values between the early and 6-month

![FIGURE 4. Plot of echocardiographic left ventricular end-diastolic dimension (LVD[DIA]), posterior free wall (LVPW) and left ventricular mass (LV mass) obtained in 39 patients before and 6 months after operation. See legend to figure 2 for abbreviations and symbols.](image-url)
TABLE 2. Serial Changes in Echocardiographic Variables (Paired Data)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preop Early postop (n = 21)</th>
<th>p</th>
<th>Early postop (n = 20)</th>
<th>6-month postop (n = 16)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV dimension (diastole)</td>
<td>76.4 ± 8.1</td>
<td>&lt; 0.01</td>
<td>60.4 ± 9.5</td>
<td>60.7 ± 10.9</td>
<td>NS</td>
</tr>
<tr>
<td>LV wall thickness (mm)</td>
<td>14.2 ± 2.0</td>
<td>NS</td>
<td>12.4 ± 5.1</td>
<td>13.2 ± 4.6</td>
<td>NS</td>
</tr>
<tr>
<td>LV mass (g)</td>
<td>724 ± 180</td>
<td>&lt; 0.01</td>
<td>483 ± 224</td>
<td>522 ± 203</td>
<td>NS</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>78.9 ± 13.6</td>
<td>&lt; 0.01</td>
<td>93.0 ± 19.3</td>
<td>79.3 ± 20.8</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

*Two patients who died in the perioperative period and three patients with evidence of operative myocardial damage (see text) are not included. These five patients had changes in LV diastolic dimension ranging from a 3-mm increase to a 6-mm decrease early postoperatively.

Abbreviations: LV = left ventricular; postop = postoperative; preop = preoperative.

Postoperative studies. Left ventricular wall thickness had not changed at either study. Most patients developed flat or paradoxical septal motion after operation; therefore, left ventricular systolic dimension and fractional shortening data are not included in table 2.

Sixteen patients had both 6-month and late postoperative echocardiograms. Little change appeared in any of the echocardiographic parameters between the 6-month study and the late postoperative study (table 2), except for one patient whose left ventricular diastolic dimension increased from 70 mm to 84 mm between 6 months and 33 months. This patient died from congestive heart failure 37 months after operation.

Mortality Experience

The results of the mortality analysis for the preoperative measurements are shown in table 3. The Cox method was developed in the mortality analysis was used for regression analysis of survival data when subjects have follow-up experience of variable length. This method is a more powerful and appropriate technique for identifying risk variables than a simple comparison of mean values for those who died and those who survived. Therefore, although mean and standard deviation values are shown in table 3, the p value indicates the predictive strength of each measurement by the Cox method.

Several preoperative echocardiographic measurements, including left ventricular end-systolic dimension, fractional shortening and ejection fraction, as well as heart rate, were associated with overall mortality (p < 0.05). Percent shortening of the left ventricle, left ventricular ejection fraction and left ventricular dimension at end-systole were all strongly associated (p < 0.01) with late deaths due to congestive heart failure. When the 10 patients with coronary artery disease are excluded, these echocardiographic measurements were still strongly associated (p < 0.01) with late deaths from congestive heart failure. Left ventricular dimension at end-diastole was also associated with late deaths from congestive heart failure (p < 0.05).

Preoperative left ventricular fractional shortening less than 25% was found in 14 of the 49 patients (29%). Nine of the 14 (64%) either died at operation (two patients) or developed symptoms of congestive heart failure and died during long-term follow-up after operation (seven patients) (fig. 5). In contrast, of 35 patients with a preoperative fractional shortening of at least 25%, one (3%) died at operation and another (3%) developed symptoms of congestive heart failure and died during long-term follow-up. The mean age of the patients with fractional shortening less than 25% (49.5 years) was slightly greater than the mean age of the patients with fractional shortening greater than 25% (45.5 years), but the difference was not statistically significant (p = 0.34).

Similar findings were noted for the left ventricular dimension at end-systole (fig. 6). Nine of seventeen patients (53%) with a preoperative end-systolic dimension greater than 55 mm either died at operation (two patients) or developed symptoms of congestive heart failure and died after operation (seven patients). This contrasts with one operative death (3%) and one late death due to congestive heart failure (3%) in the 32 patients whose dimension was 55 mm or less.

The fractional shortening data and the follow-up experience for the 17 patients who had a preoperative end-systolic dimension greater than 55 mm are summarized in figure 7 and table 4. All 17 patients had a subnormal fractional shortening (i.e., < 29%). Four of the 17 patients (24%) had a preoperative left ventricular fractional shortening of at least 25%. Eleven of the 13 patients (85%) with a preoperative end-systolic dimension greater than 55 millimeters and a preoperative fractional shortening less than 25% are either dead (nine patients) or, if still alive, have reduced left ventricular systolic function and symptoms of congestive heart failure postoperatively (two patients).

A left ventricular ejection fraction (by echocardiography using the cubed assumption) less than 58% also identified patients with a high risk of developing
congestive heart failure and dying. Also, pulmonary artery wedge pressure was associated with late deaths related to congestive heart failure, but with a lower correlation (table 3).

The results of the analysis for the measurements obtained during study 6 months after operation are also shown in table 3. Late deaths due to congestive heart failure were strongly associated ($p < 0.001$) with postoperative left ventricular end-diastolic dimension. Pre- and postoperative left ventricular diastolic dimensions are shown in figure 8. Postoperative diastolic dimension was a stronger predictor of subsequent late death from congestive heart failure than the preoperative value. Death from congestive heart failure occurred in five of seven patients with postoperative diastolic dimensions of 70 mm or greater. Moreover, as was the case preoperatively, late deaths due to congestive heart failure were also strongly associated ($p < 0.001$) at 6-month postoperative study with left ventricular fractional shortening and left ventricular dimension at end-systole (table 3), despite the questionable validity of

### Table 3. Relation of Preoperative and Postoperative Data to Overall and Late Congestive Heart Failure Mortality

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative data</th>
<th>Late CHF deaths</th>
<th>6-month postoperative data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alive (n = 35)</td>
<td>All deaths (n = 14)</td>
<td>Late CHF deaths (n = 8)</td>
</tr>
<tr>
<td>Echo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV dimension (diastole) (mm)</td>
<td>73 ± 7</td>
<td>75 ± 10</td>
<td>80 ± 7*</td>
</tr>
<tr>
<td>LV dimension (systole) (mm)</td>
<td>51 ± 8</td>
<td>59 ± 13*</td>
<td>66 ± 10†</td>
</tr>
<tr>
<td>LV fractional shortening (%)</td>
<td>29 ± 8</td>
<td>22 ± 9‡</td>
<td>18 ± 7‡</td>
</tr>
<tr>
<td>LV ejection fraction (%)</td>
<td>64 ± 10</td>
<td>51 ± 16†</td>
<td>44 ± 13‡</td>
</tr>
<tr>
<td>LV wall thickness (mm)</td>
<td>14 ± 2</td>
<td>14 ± 2</td>
<td>13 ± 2</td>
</tr>
<tr>
<td>LV mass (g)</td>
<td>655 ± 162</td>
<td>636 ± 238</td>
<td>723 ± 175</td>
</tr>
<tr>
<td>Aortic root dimension (mm)</td>
<td>37 ± 5</td>
<td>35 ± 3</td>
<td>35 ± 3</td>
</tr>
<tr>
<td>Left atrial dimension (mm)</td>
<td>45 ± 4</td>
<td>47 ± 6</td>
<td>47 ± 5</td>
</tr>
<tr>
<td>ECG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Romhilt-Estes score</td>
<td>5.4 ± 3.9</td>
<td>7.0 ± 2.6</td>
<td>6.6 ± 2.9</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>80 ± 6</td>
<td>90 ± 20†</td>
<td>83 ± 20</td>
</tr>
<tr>
<td>Hemodynamics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV pressure (systole) (mm Hg)</td>
<td>143 ± 34</td>
<td>146 ± 30</td>
<td>134 ± 18</td>
</tr>
<tr>
<td>LV pressure (end-diastole) (mm Hg)</td>
<td>22 ± 11</td>
<td>26 ± 10</td>
<td>30 ± 10</td>
</tr>
<tr>
<td>Aortic pressure (diastole) (mm Hg)</td>
<td>53 ± 9</td>
<td>52 ± 10</td>
<td>53 ± 11</td>
</tr>
<tr>
<td>PA wedge pressure (mm Hg)</td>
<td>17 ± 8</td>
<td>21 ± 8</td>
<td>24 ± 9*</td>
</tr>
<tr>
<td>PA pressure (systole) (mm Hg)</td>
<td>40 ± 16</td>
<td>40 ± 14</td>
<td>42 ± 16</td>
</tr>
<tr>
<td>PA pressure (diastole) (mm Hg)</td>
<td>16 ± 8</td>
<td>19 ± 7</td>
<td>22 ± 6</td>
</tr>
<tr>
<td>Cardiac index (l/min/m²)</td>
<td>2.6 ± 0.5</td>
<td>2.6 ± 0.6</td>
<td>2.7 ± 0.4</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronary artery disease (percent of patients)</td>
<td>20%</td>
<td>21%</td>
<td>13%</td>
</tr>
<tr>
<td>Age (years)</td>
<td>45 ± 13</td>
<td>49 ± 15</td>
<td>47 ± 14</td>
</tr>
</tbody>
</table>

Values are mean ± sd.
Postoperative left ventricular systolic dimension, fractional shortening and ejection fraction are in parentheses because most patients developed abnormal septal motion after operation.
Statistical significance determined by the Cox method of life-table analysis *:
* $p < 0.05$;
† $p < 0.01$;
‡ $p < 0.001$.
Abbreviations: LV = left ventricular; CHF = congestive heart failure; PA = pulmonary artery.
these latter measurements as a precise index of left ventricular contractile function because of the postoperative development of abnormal septal motion in the majority of the patients. Other variables associated with late deaths from congestive heart failure were estimated left ventricular mass, left ventricular systolic pressure, cardiac index and heart rate.

**Discussion**

The results of this prospective study show that the most striking abnormality in patients with longstanding aortic regurgitation was left ventricular dilatation, manifested by increases in both the end-diastolic and end-systolic dimensions of the left ventricle. Left ventricular fractional shortening was normal in many patients, but occasionally was reduced markedly. These findings are consistent with previous angiographic and echocardiographic studies. The aorta and left atrium also were dilated.

After replacement of the aortic valve, the internal dimensions of the left ventricle decreased in nearly every patient. In contrast, left ventricular

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**Figure 5.** Preoperative left ventricular fractional shortening. The 35 patients who are known to be alive (32 patients) or lost to follow-up (three patients) are shown in the far-left column (open symbols). The three patients who died at operation (OP) are shown in the left-middle column, the eight who died late of congestive heart failure (CHF) are shown in the far-right column, and the three whose late deaths are unrelated to CHF are shown in the right-middle column (filled symbols). The patients with coronary artery disease are identified by a diagonal line, including the patient who died during a subsequent coronary bypass operation (CABG) and the patient who died of an acute myocardial infarction (M1). The normal range is shown by the stippled area.

**Figure 6.** Preoperative left ventricular end-systolic dimension is shown for the same 49 patients in figure 5. See legend to figure 5 for a description of the four patient groups and abbreviations.
wall thickness did not change appreciably after operation. Estimated left ventricular mass decreased in nearly every patient as a result of the decrease in left ventricular internal dimension, but rarely returned to normal. Serial evaluation of the left ventricle after operation revealed that most of the changes in the left ventricular internal dimensions occurred early after operation. In fact, when the left ventricular end-diastolic dimension failed to decrease significantly (i.e., 11 mm or more) by the time of early study (8–22 days) after operation, patients either died in the perioperative period or had evidence of myocardial damage by electrocardiography or contrast angiography.

Echocardiographic evaluation of the size and function of the left ventricle is potentially problematic. One problem involves inferring overall size and function of the left ventricle from measurements made at its base. Five patients in the present series had an area of ventricular dyskinesia noted on cineangiograms before operation. However, both echocardiographic and angiographic assessments indicated good left ventricular function in these five patients. A few patients developed new ventricular dyskinesia after operation, but, most patients had symmetrical ventricular contraction both before and after operation (except for a small region of akinesia postoperatively at the site of the apical vent).

Another problem is that the markedly dilated ventricle is more spherical than normal,23 and measurements of ventricular size at the tip of the mitral leaflets therefore yield different values than measurements obtained below the tips. In the present study, assessment of the size and function of the left ventricle was standardized by making measurements when the ultrasound beam was passing through the left ventricle below the tips of the mitral leaflets. Also, the T-scan technique27 was used in order to identify the maximum left ventricular end-diastolic dimension. By using the largest measurement, variations in heart size due to respiration were minimized.32

Estimation of left ventricular mass from measurements at the base of the heart also contains many sources of error. The changes in mass reported in this study, however, are similar to those reported by Kennedy et al.25 and Pantely et al.26 using angiographic methods.

Nonetheless, preoperative echocardiographic evaluation of symptomatic patients with aortic regurgitation identifies factors strongly associated with death after aortic valve replacement. For example, echocardiographic assessment of left ventricular fractional shortening and end-systolic dimension identifies patients at high risk of developing congestive heart failure and dying after operation despite successful valve replacement. The high-risk group is identified by preoperative values of left ventricular fractional shortening less than 25% and left ventricular end-systolic dimension greater than 55 mm (figs. 9 and 10). Nine of 13 patients (69%) who fell into this group preoperatively either died at operation or late postoperatively of congestive heart failure. These associations support previous suggestions that late deaths due to congestive heart failure after successful operation in symptomatic patients with aortic regurgitation result from left ventricular systolic.

**Figure 7. Diagram of the follow-up experience in 17 patients with a preoperative left ventricular end-systolic dimension (LVDS) > 55 mm. % FS = left ventricular fractional shortening; CHF = congestive heart failure.**

![Diagram of the follow-up experience in 17 patients with a preoperative left ventricular end-systolic dimension (LVDS) > 55 mm. % FS = left ventricular fractional shortening; CHF = congestive heart failure.](image-url)
TABLE 4. Seventeen Patients with Preoperative Left Ventricular Systolic Dimension > 55 mm

<table>
<thead>
<tr>
<th>Pt</th>
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<th>Sex</th>
<th>CAD</th>
<th>LVD (D) (mm)</th>
<th>LVD (S) (mm)</th>
<th>FS (%)</th>
<th>LVEDP (mm Hg)</th>
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*Myocardial damage at operation (see text).
Abbreviations: IS = iceed saline; CP = coronary perfusion; SE = Starr-Edward prosthesis; BSh = Björk-Shiley prosthesis; LVD = left ventricular dimension at end-diastole (D) and end-systole (S); FS = fractional shortening; CAD = coronary artery disease; CHF = congestive heart failure; LVEDP = left ventricular end-diastolic pressure; + = present; 0 = absent.

Dysfunction that had developed before operation because of the long-standing and severe left ventricular volume overload. Preoperative diastolic dimension of the left ventricle is also associated with late death from congestive heart failure, but it is not as sensitive a predictor as measurements of left ventricular systolic size and function.

The end-systolic dimension and the degree of systolic shortening of the left ventricle were both good measurements for predicting late deaths due to congestive heart failure. These measurements were closely associated (fig. 9) and both reflect the systolic function of the left ventricle. The left ventricular end-systolic dimension alone is a less powerful preoperative predictor than it is when combined with fractional shortening (53% of congestive failure deaths when end-systolic dimension exceeded 55 mm vs 69% when end-systolic dimension exceeded 55 mm and fractional shortening was less than 25%).

All patients operated upon in this series had either severe dyspnea on exertion, angina, syncope or evidence of overt left ventricular failure (orthopnea, paroxysmal nocturnal dyspnea or one or more episodes of pulmonary edema). Hence, while we have shown that several echocardiographically derived indices are predictive of late death due to congestive heart failure in patients with moderate-to-severe symptoms, different results might be found in patients with echocardiographic evidence of severe left ventricular dysfunction who were operated upon with no symptoms or with mild symptoms. Because the patients in this series had long-standing aortic regurgitation, our results are not applicable to the patient with acute aortic regurgitation.

As there were only three operative deaths, a statistical analysis of operative mortality was not performed. However, two of the three patients who died at operation had a left ventricular fractional shortening less than 25% and a left ventricular dimension at end-systole greater than 55 mm. Moreover, it appears that the large and poorly functioning left ventricle may be more susceptible to operative damage. Preoperative left ventricular fractional shortening was less than 25% and end-systolic dimension was greater than 55 mm in five of the nine patients with operative damage, as evidenced by electrocardiographic evidence of myocardial infarction, new postoperative wall motion abnormalities or low output deaths. Only one of these nine patients had coronary artery disease.

Echocardiographic assessment of global left ventricular systolic function after operation is subject to additional sources of potential error because of the development of abnormal septal motion. It is clear, however, that the diastolic size of the left ventricle at 6-month postoperative study was even more strongly associated with late congestive heart failure deaths than was the preoperative value (fig. 8). Thus, severe ventricular dilatation that persisted after technically successful valve replacement identified patients at high risk of late death from congestive heart failure. Moreover, despite the questionable relationship between postoperative left ventricular fractional shortening and actual left ventricular systolic function (because of abnormal septal motion), the post-
operative left ventricular fractional shortening and end-systolic dimension were also valuable in identifying patients at high risk of late death from congestive heart failure. Hemodynamic data indicated that the left ventricular systolic pressure and the cardiac index were significantly reduced at the 6-month postoperative study in patients who died late after operation of congestive heart failure. Thus, at the 6-month postoperative study, patients whose subsequent deaths were related to congestive heart failure had large, poorly contracting left ventricles that appeared to have an impaired ability to generate pressure and stroke volume.

The presence or absence of coronary artery disease was not significantly associated with mortality, perhaps in part because only 10 patients had coexistent coronary artery disease. Of these 10, four had saphenous vein bypass grafts. Thus, the number of patients who had valve replacement and unoperated coronary artery disease is too small to draw meaningful conclusions.

In summary, the results of this study show that echocardiography provides preoperative data that can be used to predict the likelihood of a good or poor

![EFFECT OF OPERATION ON LEFT VENTRICULAR DIMENSION AT END-DIASTOLE](image)

**Figure 8.** Left ventricular end-diastolic dimension in the 39 patients with echocardiographic measurements before and 6 months after operation. Large open circles with horizontal bars indicate mean values. See legend to figure 5 for a description of the three patient groups. Two patients died from congestive heart failure (CHF) before postoperative study. Their preoperative data are shown (open circles in far right column) but not included in the mean. MI = myocardial infarction; CABG = coronary artery bypass graft.
result after operation in symptomatic patients with aortic regurgitation; the systolic size and function of the heart appear to be the most powerful predictors. Specifically, when the left ventricular percent fractional shortening is less than 25%, and the internal dimension of the left ventricle at end-systole is greater than 55 mm, the chances of suffering perioperative myocardial damage appear to be increased, and the risk of developing congestive heart failure and dying several months to years after operation is high. As a result of this study and follow-up data obtained in initially asymptomatic patients with aortic regurgitation (and reported in a separate manuscript), we have changed our approach to the patient with aortic regurgitation and now recommend operation not only to symptomatic patients, but also to asymptomatic patients whom we believe are at high risk because of severe left ventricular systolic dysfunction.

**Acknowledgment**

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