Echocardiographic Assessment of Left Ventricular Outflow Width in the Selection of Mitral Valve Prosthesis

By NAVIN C. NANDA, M.D., RAYMOND GRAMIAK, M.D., PRAVIN M. SHAH, M.D.,
JAMES A. DEWESEE, M.D., AND EARLE B. MAHONEY, M.D.

SUMMARY
Assessment of left ventricular outflow tract (LVO) width was made from preoperative mitral valve echocardiograms in 26 patients with pure or predominant mitral stenosis who later had valve replacement. LVO width was measured as the minimum space between the ventricular septal echo and the anterior mitral leaflet at beginning systole. Prosthesis encroachment on LVO (PE) was estimated by comparing the length of the poppet expected to protrude into the LVO in systole with LVO width determined by ultrasound (poppet length/LVO width × 100). Group 1 (12 patients) had normal LVO widths (≥20 mm) and received Starr-Edwards prostheses. There was one in-hospital death in this group. Group 2 (seven patients) had narrow LVO (<20 mm) and also received Starr-Edwards prostheses. Five patients died, four of them due to low cardiac output syndrome. Group 3 (seven patients) also had narrow LVO, but Cross-Jones disc prostheses were used. Only one died. The high mortality in Group 2 appears to be related to obstruction of LVO by the caged ball prosthesis; PE in this group ranged from 60% to 80% while it was less than 50% in all but two patients in Group 1. A low profile prosthesis appears desirable when the LVO width measures <20 mm by echocardiography.

Additional Indexing Words:
Echocardiography Cross-Jones prosthesis Starr-Edwards prosthesis
Mitral valve echocardiogram Low cardiac output syndrome Mitral stenosis

An important consideration in mitral valve replacement is the selection of a prosthesis which can be easily accommodated in the cavity of the left ventricle. An unduly large prosthesis may project far enough into the left ventricle to obstruct the outflow tract or to irritate the ventricular septum or free wall. It is thus useful to know the size of the outflow tract of the left ventricle so that a suitable prosthesis may be inserted. A noninvasive, nonionizing technique like echocardiography would be welcome if it could provide this information. The purpose of this report is to evaluate the usefulness of ultrasonic measurement of the width of the left ventricular outflow tract in selecting the type of mitral prosthesis to be used for valve replacement in patients with pure or predominant stenosis.

Material and Methods
Twenty-six patients undergoing mitral valve replacement were studied by echocardiography. All had pure or predominant mitral stenosis. There were 21 females; the rest were male. Their ages ranged from 30 to 65 years, the average being 47 years. Patients with associated disease of other valves as well as patients with clinically evident ischemic heart disease were excluded from the study. The cardiac index, determined by the dye method at cardiac catheterization prior to surgery, was low (<2.7 L/min/m²) in 21 patients and was in the low normal range in the remainder.

In all patients mitral valve echograms were obtained before surgery by placing the transducer in the third or fourth intercostal space and angling posteriorly and slightly medially. All echograms were obtained using commercially available equipment (Picker) and a 2.0 MHz transducer. Continuous records were obtained using a Fairchild oscilloscope record camera and 35 mm film. The width of the left ventricular outflow tract, which is the space between the left side of the ventricular septum and the anterior mitral leaflet, was measured in millimeters at the beginning of systole.
(fig. 1). Measurements were obtained from different transducer positions and the minimum width of the outflow tract was noted. LVO widths of less than 20 mm were considered indicative of a narrow outflow tract (measurement in normals ranges from 20 to 35 mm) (fig. 2). From the data supplied by the manufacturer of the Starr-Edwards prosthesis, the length of the cage and of the poppet expected to project into the left ventricular outflow tract in systole following valve implantation (fig. 3) were measured in millimeters and compared with the width of the left ventricular outflow tract obtained by ultrasound (poppet length/LVO width × 100). A similar comparison was made using the Cross-Jones prosthesis.

The postoperative in-hospital clinical course of each patient was analyzed from the patient chart by independent observers. Careful attention was directed to the development of low cardiac output as well as to the appearance and frequency of ventricular arrhythmia early in the postoperative period. Only patients showing persistent evidence of low systemic arterial blood pressure and signs of poor peripheral perfusion with low urinary output were considered as having low cardiac output syndrome. The cause of death as evaluated clinically or at autopsy was noted in patients who died within 30 days following surgery.

**Results**

Nineteen patients had Starr-Edwards mitral valve replacement (four had valves of 6300 series, one 6120 series, nine 6310 series and five 6320 series). A low profile prosthesis (Cross-Jones Disc Valve) was inserted in the remaining seven patients. The selection of the type of prosthesis in these patients was made by the operating surgeon based on his estimate of the ventricular outflow size at the time of surgery. Patients were divided into three groups (table 1). Both Groups 1 and 2 consisted of patients who received Starr-Edwards prostheses. Group 1 consisted of 12 patients whose left ventricular outflow tract width was normal (20 mm or more) by the echocardiographic method. The measurement in all but two in this group was 25 mm or more. Group 2 consisted of seven patients who received caged ball prostheses and had narrow left ventricular outflow tracts (less than 20 mm) by echocardiography. All in this group measured between 15 and 19 mm. Group 3 consisted of seven patients whose outflow tracts fell in the narrow range and who received a low profile prosthesis (Cross-Jones). The mean age and preoperative cardiac index of the patients in each group were comparable.

The surgical technique used in all patients was similar. Intermittent aortic cross-clamping was used for periods not exceeding ten minutes in only five out of 19 patients who received Starr-Edwards prostheses. Three of these are in Group 1 while the remaining two are Group 2 patients. In no patient did the cross-clamping time exceed 34 minutes. Myocardial cooling to 30°C was employed in all patients. The duration of myocardial cooling and of the cardiopulmonary bypass period are comparable in Groups 1 and 2 (table 2). None of the patients developed obvious evidence of myocardial ischemia during surgery as indicated by prominent ST changes or serious arrhythmias.

Possible encroachment into the left ventricular outflow tract by the caged ball prosthesis was estimated by comparing the known length of the portion of the ball expected to project into the left ventricular cavity in systole with the ultrasonically obtained width of the outflow tract (table 3). In Group 2 patients, the ball size could have occluded 60% to 80% of the outflow tract of the left ventricle while it constituted less than half the outflow width in 10 out of 12 patients in Group 1. Also, the length of the cage protruding into the left ventricular cavity was greater than the outflow width in all patients in Group 2, thus increasing the

**Table 1**

<table>
<thead>
<tr>
<th>Patient category</th>
<th>LVO width (mm)</th>
<th>Prosthesis type</th>
<th>Mean age (years)</th>
<th>Preoperative cardiac index (L/min/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(12 patients)</td>
<td>20 or more</td>
<td>Caged ball</td>
<td>44.18</td>
<td>1.72 – 3.19</td>
</tr>
<tr>
<td></td>
<td>Range 20 – 32</td>
<td></td>
<td></td>
<td>Mean 2.44; SE 0.13</td>
</tr>
<tr>
<td></td>
<td>Mean 26.3; SE 0.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td>Less than 20</td>
<td>Caged ball</td>
<td>48.6</td>
<td>1.20 – 3.86</td>
</tr>
<tr>
<td>(7 patients)</td>
<td>Range 15 – 19</td>
<td></td>
<td></td>
<td>Mean 2.63; SE 0.45</td>
</tr>
<tr>
<td></td>
<td>Mean 16.86; SE 0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3</td>
<td>Less than 20</td>
<td>Low profile</td>
<td>48.1</td>
<td>2.39 – 2.99</td>
</tr>
<tr>
<td>(7 patients)</td>
<td>Range 14 – 19</td>
<td></td>
<td></td>
<td>Mean 2.52; SE 0.15</td>
</tr>
<tr>
<td></td>
<td>Mean 18.14; SE 0.70</td>
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</tbody>
</table>

LVO width = left ventricular outflow tract width by ultrasound. SE = standard error.
Figure 1
Mitral valve (MV) echocardiogram from a patient with mitral stenosis. The space between the ventricular septum (VS) and the anterior mitral leaflet forms the left ventricular outflow tract (LVO). Its width was measured in mm at the onset of systole (indicated by arrows). PHONO = phonocardiogram; ECG = electrocardiogram.

Figure 2
Mitral valve echocardiograms from two patients with mitral stenosis. The echogram on the left demonstrates a narrow left ventricular outflow tract (LVO) while the one on the right illustrates a normal sized outflow tract. RESP = respirations; PHONO = phonocardiogram; ECG = electrocardiogram.
Figure 3

Diagrammatic representation of a Starr-Edwards caged ball prosthesis. 1: Length of the portion of the poppet expected to be projecting into the left ventricular outflow tract in the closed position (in systole) following prosthesis implantation. 2: Height of the cage.

likelihood of interference with ventricular contraction. On the other hand, the cage height measured more than the ultrasonically determined width of the outflow tract in only two out of 12 patients in Group 1. The cage height of the Cross-Jones valve was less than the left ventricular outflow tract dimension in every patient who received this prosthesis. The thickness of the Cross-Jones lens used in Group 3 patients measured 2 mm and hence the disc itself would not be expected to produce any significant obstruction to the left ventricular outflow.

The in-hospital mortality rate was relatively low and comparable in Groups 1 and 3 (Table 4). Of the two who died, one succumbed during surgery of a technical error and the other patient suffered a myocardial infarction. Five of seven patients in Group 2 (caged ball prosthesis and narrow left ventricular outflow tract by ultrasound), died soon after surgery (within 2 to 15 days). In four, low cardiac output syndrome was judged to be the main cause of death. In the remaining one, postoperative respiratory complications were the main cause of death. The high mortality in Group 2 is impressive when compared to the relatively low mortality in Group 1 ($P < 0.01$) and Group 3 ($P < 0.05$).

Discussion

Echocardiography is a noninvasive technique which does not pose any risk to the patient. Its usefulness in evaluating the state of the mitral valve is well established.6-9 The left ventricular outflow tract has been identified in a previous study from our laboratory using indocyanine green.10 This dye has been shown to produce a thick cloud of echoes when injected into cardiac chambers during cardiac catheterization. For example, in patients with aortic regurgitation, injection of this agent into the aortic root outlines on mitral valve echograms the left ventricular outflow tract as it fills with dense echoes from the regurgitating dye (fig. 4). Evaluation of the width of the left ventricular outflow tract by echocardiography has been used to demonstrate narrow outflow tracts in hypertrophic obstructive cardiomyopathy (idiopathic hypertrophic subaortic stenosis)11 and ostium primum atrial septal defect.12 The left ventricular outflow space may vary somewhat (up to 3–4 mm) with transducer angulation, being reduced when angling towards the aortic root and increased when echoing deeper towards the ventricular cavity. This variation in the width of the space probably occurs as a result of bowing or bending of the septum as it attaches to the base of the aorta. Therefore it is important to take the minimal width obtained on the echogram as the LVO measurement.

The relatively extensive experience with the caged ball prosthesis, the recent improvements in

<table>
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<th>Table 4</th>
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<tr>
<td><strong>Comparison of Surgical Technique</strong></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>12 patients</td>
</tr>
<tr>
<td>Group 2</td>
</tr>
<tr>
<td>7 patients</td>
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</tbody>
</table>

SE = standard error.

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Table 4

Post-Operative Mortality

<table>
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<tr>
<th>Patient category</th>
<th>In-hospital mortality</th>
<th>Cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal LVO and caged ball prostheses</td>
<td>8%</td>
<td>intra-operative</td>
</tr>
<tr>
<td>(12 pts.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrow LVO and caged ball prostheses</td>
<td>71%</td>
<td>respiratory</td>
</tr>
<tr>
<td>(7 pts.)</td>
<td></td>
<td>complications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 low output state</td>
</tr>
<tr>
<td>Narrow LVO and low profile prostheses</td>
<td>14%</td>
<td>recent myocardial</td>
</tr>
<tr>
<td>(7 pts.)</td>
<td></td>
<td>infarction</td>
</tr>
</tbody>
</table>

LVO = left ventricular outflow tract.

its design, and the low complication rate are the main reasons for routinely using this type of prosthesis instead of a low profile device for mitral valve replacement. However, certain complications may follow the implantation of the relatively large caged ball prosthesis into a ventricle with a narrow outflow tract. Protrusion of the bulky valve apparatus into the left ventricular cavity may obstruct the left ventricular outflow tract leading to low cardiac output syndrome. The struts of the prosthesis may irritate the ventricular septum or the posterolateral wall causing arrhythmia. Protrusion of the muscular ventricular septum into the cage may restrict motion of the ball in diastole leading to obstruction to left atrial emptying with subsequent thrombosis.

That the problem is by no means a small one is suggested by some recent studies. As many as 14 out of 46 patients who died within two months following mitral valve replacement were concluded to have prosthetic dysfunction from disproportion between the size of the prosthesis and the left ventricle. In another study, the left ventricular cavity appeared to be too small to accommodate a

Figure 4

Mitral valve (MV) echocardiogram obtained during injection of indocyanine green into the aortic root in a patient with aortic regurgitation. The left ventricular outflow tract (LVO) is outlined by dense echoes produced by the dye as it regurgitates into the outflow area. The arrow indicates the arrival of these echoes in early diastole. VS = ventricular septum; PHONO = phonocardiogram; ECG = electrocardiogram.
caged prosthesis in seven out of 51 patients undergoing mitral valve replacement.\textsuperscript{15}

Knowledge of the size of the outflow tract prior to surgery can be useful to the surgeon who must decide whether a low profile prosthesis is indicated in a given patient undergoing mitral valve replacement. Routine left ventricular angiograms performed to evaluate either the degree of mitral regurgitation or ventricular function do not always provide reliable information about the dimension of the outflow tract. Special studies in steep LAO position are required for adequate visualization. Even during open-heart surgery, the outflow tract may appear to be larger than it really is, particularly in the presence of hypothermia, ischemic arrest or ventricular fibrillation. At necropsy, the relation of the cage and ball to the ventricular septum is difficult to assess accurately when hearts containing mitral valve prostheses are opened in routine fashion. Radiographs of the intact heart and serial transverse sections cut parallel to the plane of the atrioventricular sulcus are needed to judge this relationship correctly and to assess any obstruction to the outflow tract of the left ventricle caused by the prosthesis.\textsuperscript{15}

In the present study it appears reasonable to postulate that the clinically evident low output state in the Group 2 patients who died was related to the bulk of the prosthesis since the poppet could have occupied more than 60\% of the available outflow diameter. In addition, the height of the cage regularly was greater than the outflow tract width and also may have interfered with ventricular contraction. The longitudinal axis of the implanted prosthetic device, seated in the mitral ring, might tend to direct the apex of the cage toward the left ventricular cavity and away from the ventricular septum. This may explain the lack of arrhythmias in our patients but should not materially alter the position of the base of the prosthesis nor of the obstructing ball in the left ventricular outflow in systole. A low profile valve, on the other hand, would be less likely to obstruct the outflow tract because of the far smaller size of the disc compared to that of the ball. This is supported by an experimental study in dogs using caged ball prostheses and low profile valves in two different groups.\textsuperscript{17} A higher mortality rate in the group in which the ball and cage prostheses were implanted was thought to be partly due to low cardiac output caused by obstruction by the ball and cage. Furthermore, a recent study of combined aortic and mitral valve disease reported a 52\% operative mortality among 40 patients in whom both valves were stenotic and the left ventricular cavity consequently of small or normal size, whereas the mortality rate was only 15\% among 84 patients in whom one or both valves were predominantly regurgitant.\textsuperscript{18}

In the present study the technical factors during surgery which could play a role in low cardiac output syndrome in the postoperative period were comparable in the two groups with Starr-Edwards prostheses and hence might be expected to be operative to the same extent in both groups.

Although the number of cases in our study is not large, it would appear that echocardiographic evaluation of the size of the left ventricular outflow tract is useful in selecting the type of mitral prosthesis to be used for valve replacement. A width of less than 20 mm by ultrasound makes it desirable to use a low profile prosthesis to avoid likelihood of mechanical encroachment of the outflow tract.

**Acknowledgment**

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**References**

7. **Edler I:** Ultrasound cardiology in mitral valve stenosis. Am J Cardiol 19: 18, 1967

*Circulation, Volume XLVIII, December 1973*
Correction


Figure 4

Case #4952. Half-axial projection. Chronic, progressive angina. Significant partial occlusive lesion in the left main coronary artery (arrow). Less critical occlusive lesions in the left anterior descending artery distal to the origin of the second septal artery, and in both diagonal branches as well. Abbreviations as in figure 1.

Figure 6

Case #4744. Half-axial projection. Unstable angina. A 90% occlusive lesion at the origin of the left circumflex artery (arrow). Minor changes in diameter of the left main coronary artery and the left anterior descending artery just distal to the origin of the circumflex division. Abbreviations as in figure 1.
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