Echocardiographic Studies of Stented Fascia Lata Grafts in the Mitral Position


SUMMARY

Nineteen patients with stented fascia lata grafts in the mitral position were studied by the reflected ultrasound technique. Eleven of these had competent grafts, two had minimal regurgitation and six had severe graft incompetence as judged by ventriculography and during surgery. The diastolic closure rate (E-F speed) of the cusps revealed significant correlation with the effective graft area derived by calculations from cardiac catheterization data (P < 0.01), and indicated only mild to moderate stenosis. The exhibited cusp mobility revealed an amplitude which was comparable with and similar to that measured in cusps from freshly prepared fascia lata valves. The demonstrated cusp mobility and E-F speed did not show a statistically significant difference between competent and incompetent grafts (P > 0.7 and P > 0.4 respectively). Further evidence is presented supporting the role played by the mitral annulus mobility in the production of echocardiographic diastolic movement of the leaflet.

Additional Indexing Words:
Effective graft area
Diastolic mitral ring mobility
Graft diastolic closure rate

ECHOCARDIOGRAPHY has become established as a noninvasive technique for the diagnosis and assessment of mitral valve stenosis.1-5 The same technique can also be used to demonstrate prolapse of valve leaflets with or without mitral incompetence.6-8 Studies with reflected ultrasound in patients with mitral prostheses have been found useful for the detection of perivalvular leak9 and dysfunction of the occluder device,10,11 and for the investigation of the mitral ring movement.12,13

There is no published report on the application of echocardiography to the assessment of mitral stented tissue grafts. The technique of mitral valve replacement with stented fascia lata grafts has been pioneered in the General Infirmary at Leeds,14 and its clinical and hemodynamic results have been reported15,16 The present echocardiographic study was performed in patients who underwent postoperative cardiac catheterization. The aim of the investigation was to seek correlations between the hemodynamic data and the ultrasonic diastolic closure rate (E-F speed) of graft leaflets, to study the relationship between the diastolic movements of the mitral graft ring and leaflets, to detect graft incompetence, and to define the mobility of the ultrasonically demonstrated cusps in relation to that measured in freshly prepared fascia lata valves.

Material and Method

A total of 19 patients were studied by reflected ultrasound. Group A (table 1) comprised 13 patients, 11 with competent grafts and two with minimal regurgitation. The patients were investigated 1.5 to 3.5 years (mean 2.9 years) postoperatively. There were seven males and six females with an age range from 31 to 54 years (mean 44 years). Group B (table 2) comprised six patients with incompetent mitral grafts who were studied two to four years (mean 2.5 years) postoperatively. Their ages ranged between 35 and 57 years (mean 45 years). Three of these patients were males and three were females.

Echocardiographic studies were performed the day before cardiac catheterization. An Ekoline 20 ultrasonoscope was employed using a 2.25 MHz (13/12 inch face diameter) transducer probe, which transmits and receives pulsed echoes at a frequency of 1000 pulses/sec. Echocardiograms were obtained by Polaroid
Table 1

Details of 13 Patients Comprising Group A and Fresh Graft Measurements*

<table>
<thead>
<tr>
<th>Data</th>
<th>Internal diameter of grafts used (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Graft no.</td>
<td>3</td>
</tr>
<tr>
<td>years since implantation</td>
<td>1.5 ± 3</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td>Echocardiographic data</td>
<td></td>
</tr>
<tr>
<td>E-F speed (mm/sec)</td>
<td>21 ± 38</td>
</tr>
<tr>
<td></td>
<td>33 ± 6</td>
</tr>
<tr>
<td>Total graft amplitude (mm)</td>
<td>17 ± 22</td>
</tr>
<tr>
<td>Amplitude of opening movement (mm)</td>
<td>20 ± 2</td>
</tr>
<tr>
<td></td>
<td>14 ± 16</td>
</tr>
<tr>
<td></td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Heart rate (beat/min)</td>
<td>84 ± 95</td>
</tr>
<tr>
<td></td>
<td>83 ± 3</td>
</tr>
<tr>
<td>Effective graft area (cm²)</td>
<td>0.88 ± 1.37</td>
</tr>
<tr>
<td>Mean diastolic gradient (mm Hg)</td>
<td>8 ± 11</td>
</tr>
<tr>
<td></td>
<td>10 ± 1</td>
</tr>
<tr>
<td>Cardiac output (L/min)</td>
<td>2.79 ± 3.35</td>
</tr>
<tr>
<td></td>
<td>3.16 ± 0.20</td>
</tr>
<tr>
<td>Mean left atrial pressure (mm Hg)</td>
<td>2 ± 8</td>
</tr>
<tr>
<td></td>
<td>5 ± 2</td>
</tr>
<tr>
<td>Mean pulmonary artery pressure (mm Hg)</td>
<td>8 ± 15</td>
</tr>
<tr>
<td></td>
<td>12 ± 2</td>
</tr>
<tr>
<td>Fresh graft measurements</td>
<td></td>
</tr>
<tr>
<td>Cusps number</td>
<td>18</td>
</tr>
<tr>
<td>Opening amplitude (mm)</td>
<td>13 ± 17</td>
</tr>
<tr>
<td></td>
<td>16 ± 0.2</td>
</tr>
</tbody>
</table>

*Data are expressed as range, mean and standard error.

photography from the oscilloscope of the instrument. The position of the mitral graft was predetermined by thoracic roentgenography and was found in the majority of patients to lay at the level of the 4th to 5th intercostal space. To obtain mitral graft echocardiograms, the ultrasonic probe was applied to the anterior chest wall of the patients, who were in a supine position, 1 to 3 cm to the left of the midsternal line. The graft ring echoes were obtained first and were confirmed by angulation of the probe to define the relation of the anterior edge of the graft to the posterior wall of the aortic root superomedially. The interventricular septum becomes the anterior wall of the aortic root. By a further change in angulation of the probe, echograms were obtained demonstrating the maximal and fastest movements of an anteriorly placed leaflet with and without graft ring or prong echoes (fig. 1). It was not possible to obtain satisfactory mitral graft echocardiograms in two patients, one of whom had kyphoscoliosis. The data obtained from these two patients were rejected.

The hemodynamic data were obtained by right and left heart catheterization with the zero level set at a reference point 5 cm posterior to the sternal angle. Cardiac output was measured by the Fick method. Mean diastolic pressure gradient across the mitral graft was obtained by planimetry of a simultaneously recorded left ventricular and left atrial or pulmonary wedge pressure at rest. Graft orifice area in cm² was obtained by using Gorlin and Gorlin's hydraulic formula and employing simultaneous left ventricular and left atrial or pulmonary wedge pressure tracings.

Selective left ventricular cineangiography was used in every patient from group A and in five patients from group B in order to assess the competence and function of the valve graft and, when present, to grade the degree of regurgitation. In the remaining patient from group B and in three others from the same group, graft appearance during re-operation confirmed the severity of incompetency noted clinically and angiographically, and provided information regarding the mechanism of incompetence and graft leaflet mobility.

Measurements

An average of at least four cardiac cycles was used as a measure of every parameter. In the mitral graft echocardiograms, an anteriorly placed leaflet is the expected reflecting interface (fig. 1e). The demonstration of two leaflets, however, was achieved in four patients (figs. 1, 2, 6). Total amplitude of graft leaflet excursions were measured as the maximal vertical distance between point C and point E in mm, the amplitude of opening movement of the cusp as the vertical distance between point D and E in mm, and...
Table 2
Details of 6 Patients Comprising Group B

<table>
<thead>
<tr>
<th>No</th>
<th>Years since</th>
<th>Graft internal diameter (mm)</th>
<th>E-F speed (mm/sec)</th>
<th>Total graft amplitude (mm)</th>
<th>Opening movement amplitude (mm)</th>
<th>Cardiac output (L/min)</th>
<th>Mean left atrial pressure (mm Hg)</th>
<th>Mean pulmonary artery pressure (mm Hg)</th>
<th>Operative finding; graft pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>26</td>
<td>39</td>
<td>19</td>
<td>14</td>
<td>4.71</td>
<td>25</td>
<td>65</td>
<td>Shrunken posterolateral and postero medial cusp</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>28</td>
<td>34</td>
<td>19</td>
<td>13</td>
<td>3.89</td>
<td>28</td>
<td>45</td>
<td>Anterior cusp detached from the frame</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>26</td>
<td>34</td>
<td>19</td>
<td>13</td>
<td>3.72</td>
<td>20</td>
<td>36</td>
<td>Shrunken postero medial cusp. Anterior slightly thickened</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>28</td>
<td>34</td>
<td>20</td>
<td>13</td>
<td>1.76</td>
<td>22</td>
<td>26</td>
<td>Slight retraction of the posteriorly placed cusps</td>
</tr>
</tbody>
</table>

Range 2-4  
Mean ± SE 2.5

The ventricular rates of 16 patients during echocardiographic studies, the day before, and during cardiac catheterization at rest were essentially the same. The standard errors between the determinations were 25, 27, and 67 mm/sec, respectively.

The probability of Results

All the ultrasonic studies were performed by one observer. The values obtained for the two consecutive applications of the probes for the total amplitude, opening movement of the cusps, and E-F speed, were revealed by Student's test for paired variants (P > 0.5, respectively). The values obtained in each patient were always reproducible (P > 0.05).

Mitral Graft Echocardiogram

The ventricular rates of 16 patients during echocardiographic studies, the day before, and during cardiac catheterization at rest were essentially the same (P > 0.03). The values obtained for the total amplitude, opening movement of the cusps, and E-F speed, were revealed by Student's test for paired variants (P > 0.5, respectively). The values obtained in each patient were always reproducible (P > 0.05).

Reproducibility of Results

All the ultrasonic studies were performed by one observer. The values obtained for the two consecutive applications of the probes for the total amplitude, opening movement of the cusps, and E-F speed, were revealed by Student's test for paired variants (P > 0.5, respectively). The values obtained in each patient were always reproducible (P > 0.05).
The significant correlation was maintained when the two patients with the minimal graft incompetence were excluded ($r = 0.7007$, $P < 0.02$). Graft areas ranged from 0.88 to 3.00 (1.73 ± 0.17) cm$^2$, and the E-F speed between 21 and 47 (37 ± 2) mm/sec. The E-F speeds and effective graft areas were 33 ± 6 mm/sec, 1.15 ± 0.14 cm$^2$ for graft size of 24 mm, 37 ± 2 mm/sec, 1.87 ± 0.21 cm$^2$ for graft size of 26 mm, and 43 ± 5 mm/sec, 2.08 ± 0.60 for graft size of 28 mm (fig. 4). Correlations between graft calculated area and either total amplitude or opening movement of the cusp was insignificant ($P > 0.1$, $P > 0.1$). The latter two parameters ranged from 16 to 28 (21 ± 1) mm and from 10 to 23 (16 ± 1) mm, respectively. In eight patients with a graft size of 26 mm, the amplitude of the opening movements of the cusps (17 ± 1 mm) were statistically similar ($P > 0.5$) to that obtained from 26 mm fresh grafts (18 ± 3 mm). A smaller number of patients with the remaining two sizes of grafts (24 and 28 mm) are depicted in table 1.

There was no statistically significant correlation between the internal diameter of the graft ring and
either the E-F speed \((P > 0.1)\) or the opening movement of the leaflets \((P > 0.1)\). In one patient with a competent graft, studied two and three years postoperatively, the E-F speed has changed from 36 to 32 mm/sec, while the amplitude has remained unchanged. Such reduction of the E-F speed was

within the limits of repeatability of this technique. The cardiac output and stroke volume (fig. 5) correlated significantly with total graft amplitude \((r = 0.6896, P < 0.01, r = 0.7059, P < 0.01, \text{respectively})\) but not with the amplitude of cusp opening movement. No significant correlation was found between the E-F speed and either the mean left atrial pressure, mean pulmonary artery pressure or end-diastolic gradient across the mitral graft. Significant correlation \((r = 0.5810, P < 0.05)\) was found between the mean diastolic gradient and E-F speed (fig. 3).

The ventricular rates during echocardiography of the six patients belonging to group B ranged from 75 to 109 \((89 \pm 5)\) beats/min. Three patients were in atrial fibrillation and the remaining three in sinus rhythm. In five patients graft incompetence was graded as severe on angiocardiography and in the remaining patient the insufficiency observed at re-operation was considered severe. The internal diameters of the grafts used were 24 mm in one patient, 26 mm in three patients and 28 mm in the remaining two patients. The total graft amplitude ranged from 19 to 25 \((22 \pm 1)\) mm and the E-F speed from 27 to 86 \((41 \pm 6)\) mm/sec. The corresponding hemodynamic data are shown in table 2. The difference of the amplitudes of total graft, cusp opening movement and E-F speed between competent and incompetent grafts was not statistically significant \((P > 0.7, P > 0.6 \text{ and } P > 0.4)\).
In one patient with graft incompetence who was studied twice at two and at three years postoperatively, the E-F speed has increased from 39 mm/sec to 53 mm/sec while the total graft amplitude has remained the same at 19 mm.

During re-operation, the mechanism of graft incompetence was found to be due to variable shrinkage of posteriorly placed cusps in three patients and torn cusp attachments in a fourth patient. The latter patient had the highest values of total amplitude (25 mm), opening movement of cusp (19 mm) and E-F speed (66 mm/sec). In one patient with incompetent graft, two cusps were demonstrated echocardiographically (fig. 6). Both cusps appeared thickened, and the anteriorly sited one had a small opening movement of 13 mm.

Mitral Graft Ring Echocardiogram

In patients from group A, the ring amplitude ranged from 4 to 11 (7 ± 1) mm and the reeding angle ranged between 22 and 41 (34 ± 2) mm/sec. Significant correlation (fig. 7) was found between E-F speed and ring reeding rate (r = 0.7151, P < 0.01). No correlation was found between the ring amplitude or the reeding rate and either the cardiac output, (P > 0.1, $P > 0.1$), stroke volume (P > 0.1, $P > 0.1$), internal ring diameter (P > 0.1, $P > 0.1$), or mean diastolic gradient across the graft (r = 0.0736, $P > 0.1$; r = 0.3165, $P > 0.1$, respectively).

**Discussion**

Hemodynamic studies in patients with mitral stented fascia lata grafts have revealed the presence of only mild to moderate obstruction to blood flow.\(^{16,19}\) Using experimental studies with pulse duplicators, such obstruction to flow was attributed to stiffness and sequential opening of the cusps.\(^{20}\) The presence of residual left ventricular myocardial disease,\(^{21,22}\) and the increased left ventricular volume,\(^{23}\) are expected to produce a further impedance to blood flow.

A relationship between the diastolic closure rate of stenosed natural mitral valves and a numerically suitable representative value of the effective valve area has been sought. A significant correlation was found between the E-F speed in mm/sec and the mitral valve area calculated by Gorlin's method.\(^{5-4}\) In the present study, a similar correlation was obtained between the effective graft area and E-F speed. The coefficient of correlation obtained here was not, however, very high, and analysis according
to the size of effective graft area leaves a small number of patients for a valid analysis. As in previous reports on stenosed natural valves, values of E-F speed slower than 35 mm/sec indicated significant obstruction to blood flow. Our results therefore confirm the usefulness of mitral echocardiography in the detection and assessment of graft stenosis.

The E-F speed and effective area did not correlate with the graft size as obtained from its internal diameter at insertion. The slowest E-F speed and smallest effective area were, however, obtained from a patient with a graft diameter of 24 mm. In all the patients with competent grafts, the calculated area was smaller than the actual primary graft area as measured at the base of the frame. In one patient in whom an initial hemodynamic study was available, the E-F speed became slightly slower on re-examination one year later, although the mobility of the demonstrated cusp has remained unchanged. It is probable that these results together are consistent with previously reported mechanisms which may produce graft stenosis such as alteration of cusp opening characteristics and development of cusp stiffness. The size of the supporting frame of the graft should of course be taken into consideration. Although there was no significant statistical correlation when all the patients from group A were tested, the sizes of the graft rings when looked at as subgroups (fig. 4) appeared to influence the effective graft area and E-F speed. However, the number of patients within the subgroups was very small for a meaningful statistical comparison. In a study on recovered grafts at autopsy or at re-operation, up to 38 months after insertion, it was found that there was no reduction in the primary or secondary orifice area due to clot deposition, tissue ingrowth or commissural adhesions. Such factors are known to cause obstruction to blood flow across mitral valve substitutes and to influence the E-F speed in diseased natural mitral valves.

Leaflet stiffness of the diseased natural mitral valve has been shown to influence the E-F speed. Anterior leaflet mobility below 15 mm as inferred from the echocardiographic total valve amplitude, has been found to indicate severe leaflet disease. The ultrasonic mobility of an anteriorly placed graft cusp in this series was comparable to that measured in vitro in freshly prepared fascia lata valves. The amplitude of cusp movements obtained from our patients did not correlate with graft ring size, and in a few instances the amplitude in vivo was smaller than the mobility measured in grafts in vitro.

Measurement of the actual thickness of valve leaflet by reflected ultrasonic techniques is not precise, but marked thickening or calcification may be detected. In this series only one patient with severe graft incompetence was shown to have similar ultrasonic criteria which indicated marked thickening or calcification of the demonstrated...
cusps (fig. 6). The graft is still in situ as the patient was not in need of re-operation. Furthermore, echocardiographic A waves were demonstrated in patients following atrial systole (fig. 1d, 8), and in one patient with grade II aortic incompetence, as determined by aortography, fast echocardiographic oscillations (fig. 9) of cusp echoes were seen. Both the A wave and the oscillations are usually absent in echocardiograms from patients with severe mitral stenosis and diseased leaflets. Echoes from only one or occasionally two cusps could be obtained, however, in the same patient, and the changes in the opening characteristics of the cusps have been shown to be limited to one or two cusps only, regardless of their circumferential orientation. The demonstration of cusps which have retained good mobility characteristics nevertheless will serve as a sensitive indicator of reduced rate of ventricular filling caused by changes in the remaining cusps. The significant correlation seen in this study between the E-F speed and effective area or the mean diastolic gradient across the graft corroborates this finding. In the two patients with graft ring diameter of 28 mm who were studied 3.5 years after insertion, the reduction of mobility of the demonstrated cusps would suggest either that the visualized cusps were those with changed opening characteristics or that the influence of a large graft size plays a role in maintaining good flow across the graft.

In disease of the natural mitral valve, echocardiographic valve amplitude and E-F speed are not always helpful in the detection or assessment of incompetence. Systolic leaflet prolapse into the left atrium may however be demonstrated. Echocardiograms in this series demonstrated anterior cusp prolapse beyond graft frame in patients with competent valves. In one patient with graft incompetence (group B, patient 1, table 2), repeat echocardiography one year later showed a significant increase in the E-F speed, but not in valve amplitude. In this patient, recovery of the graft at re-operation revealed retraction and shrinkage of the two posteriorly placed cusps but not of the anterior one which was demonstrated echocardiographically. In another patient (group B, patient 3, table 2), whose graft incompetence was found to be due to detachment of the anterior cusps from the frame, the E-F speed was the fastest in this series and valve amplitude was large. In a third patient (group B, patient 5, table 2, fig. 6) with severe graft incompetence, cusp thickening was demonstrated with reduced opening movement amplitude, probably suggesting a diseased cusp as the cause of incompetence. These features and their progress in time may help to detect significant graft incompetence if they are further confirmed by studying a larger series. Our data revealed no significant statistical difference between graft or cusp opening amplitudes or E-F speed of severely incompetent grafts when compared with competent ones.

In this study a significant correlation was found between the E-F speed of the graft cusp and the diastolic receding rate of the graft ring. The former

![Figure 8](image1)

**Figure 8**

Echocardiograms obtained from a patient with a size 26 mm, competent autologous fascia lata mitral graft, three years after insertion. Frame a shows aortic root echocardiogram in relation to frame b demonstrating mitral graft echocardiogram. Echocardiographic A wave can be seen in frame b. Abbreviations as in figures 1 and 2.

![Figure 9](image2)

**Figure 9**

Mitral graft echocardiogram from a patient with a size 28 mm competent homologous fascia lata mitral graft, 3.5 years after insertion. This patient also had aortic incompetence. Fine rapid oscillation can be seen on the demonstrated cusp echo.
has exceeded the latter in the majority of the patients. These results confirm previous works suggesting that mitral ring movement and ring vortex formation beneath the valve cusps are the mechanisms of the diastolic closure movement.12, 23, 32

Echocardiography of the stented fascia lata grafts was found useful in the assessment of the effective valve area and its changes in time. Cusp retraction and stiffness which subsequently give rise to incompetence was demonstrated. Furthermore, individual observations suggest that when an unaffected cusp is visualized ultrasonically, the development of a faster E-F speed would indicate progression of graft incompetence. A single determination of the E-F speed, however, did not appear to be helpful in detecting incompetence.

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