Echocardiographic Determination of Mitral Disc Valve Excursion

By Michael L. Johnson, M.D., Joseph H. Holmes, M.D., and Bruce C. Paton, M.D.

SUMMARY
Disc excursion and opening and closing velocities of prosthetic disc valves can be measured accurately by diagnostic echocardiography. The ultrasound beam is projected along the longitudinal axis of the valve and the echoes arising from the struts, disc, and suture ring are displayed on the oscilloscope. Twenty-four patients with normally functioning mitral Beall valves of various sizes and three patients with prosthetic valve dysfunction (one Beall, two Kay-Shiley) were studied. Table 1 lists the disc excursions with standard deviations of Beall valves measured by ultrasound.

The 0.06-0.09 cm difference in excursion between models no. 103 and no. 104 valves was detected by ultrasound without prior knowledge of change in design of the valve and demonstrates the extreme accuracy of this technic. The opening and closing disc velocity averaged 22 cm/sec and 40 cm/sec, respectively.

Decrease in expected disc excursion and abnormal motion patterns were found in three patients with prosthetic dysfunction secondary to thrombus formation, and verified at operation. With continuous changes in valve designs it is important to obtain a baseline excursion and motion pattern for each patient immediately postoperatively.

Echocardiography is a useful, noninvasive, reproducible technic for accurate assessment of prosthetic mitral disc valve movement.

Additional Indexing Words:
Ultrasound Diagnostic echocardiography Beall valve Prosthetic valve Kay-Shiley valve Prosthetic valve dysfunction

ULTRASOND is one of several technics now available for the assessment of prosthetic valve function. Several authors have described the motion patterns of Starr-Edwards prosthetic valves.1-4 In a previous paper the authors described an in vitro system for analyzing motion patterns obtained from various prostheses and defined the different echo tracings obtained from discs of different acoustic density.3

With increasing use of disc and other low-profile artificial valves in the mitral position, a second study was initiated to determine the usefulness of ultrasound in evaluating these valves. This present study describes the echo patterns obtained from various sizes of Beall valves and outlines a method for analysis of the motion pattern in relation to the function of the valve. Associated clinical studies include three examples of disc valve malfunction.

Methods
The characteristic echo pattern of the Beall valve was first established in an in vitro system previously described.5

The ultrasonic unit used in this study was a Physionics, type 564 storage oscilloscope with a lead zirconate, flat-faced, 2.25 mHz transducer, 1.6 cm in diameter. A 502 dual-beam oscilloscope was used as a monitor to display ultrasonic echoes in time-motion synchronously with the patient's electrocardiogram. A Polaroid camera was used for making permanent records from the 504 dual-beam during time-motion mode displays. In more recent studies, a model 100 series diagnostic ultrasound system made by Unirad Corporation has been used.

Twenty-four patients with normally functioning Beall mitral valves of various sizes were studied, many of them on two or more occasions for a total of 40 ultrasonic examinations. Three patients with prosthetic
valve dysfunction were also evaluated. The patients were examined supine with the head elevated 20°–30°. The transducer was placed at the cardiac apex and directed upward and medially toward the mitral annulus along the longitudinal axis of the valve. When the prosthetic valve was located the display was magnified to visualize better the excursion of the disc within the struts. Using the "A" mode display the transducer was aligned such that echoes from the anterior strut, anterior surface of the disc, and suture ring of the valve were all maximum in amplitude and did not change in amplitude during the cardiac cycle. Pictures were then taken of the time-motion display and the ultrasonic unit carefully calibrated for each patient.

Results

Figure 1 shows three echo traces obtained from a medium-sized Beall valve mounted in vitro. The valve cage was stationary and the Teflon disc was moved back and forth by action of the pump. Echo traces 1 and 3 are straight lines and represent one of the anterior struts and the suture ring, respectively. The Beall valve has two struts and only one is visualized at any one time. Trace 2, which moves up to and away from trace 1, is from the anterior surface of the moving disc. It is possible to demonstrate the posterior surface of the disc, but this measurement has not been found to be of clinical significance and is not usually made. Traces 1 and 2 from a Beall valve are very similar to those from a Starr-Edwards prosthesis.

Figure 2 is a typical echo tracing obtained from a patient with a medium-sized Beall valve. A simultaneous electrocardiogram demonstrates that with ventricular systole the disc (trace 2) moves rapidly away from the anterior strut (trace 1) and remains in a closed position throughout systole with traces 1 and 2 equidistant from each other. During this time the entire valve moves toward the transducer because of movement of the mitral annulus. With diastole and opening of the valve, the anterior disc echo moves forward and merges with the echo from the anterior strut. The valve remains open throughout diastole and the entire valve and mitral annulus move away from the transducer during ventricular filling. The third echo trace is that from the suture ring of the valve. Because the suture ring and annulus are attached to each other, their motion patterns are identical, and parallel that of the strut.

Figure 3 demonstrates the technic used to measure disc excursion and opening and closing velocities. Measurement of the distance between the most anterior aspects of the strut echo and disc echo, while the valve is closed, gives the maximum closing excursion of the disc. As this measurement includes the width of the strut, it is slightly larger than the actual excursion of the disc within the cage. A decrease in this measurement would indicate incomplete closure or seating of the disc against the suture ring from whatever cause. Incomplete opening of the valve can be detected by failure of the disc echo to merge with the echo of the anterior strut during diastole. Because there are two struts on the Beall valve, thrombus may form on only one strut, restricting excursion of only one edge of the disc. Therefore, measurements must be made over both struts during examination. This is accomplished by angulation of the sound beam from one strut to the other.

Opening and closing velocities are calculated from the slope of the trace from the anterior disc as

Figure 1

In vitro ultrasound tracing from a Beall disc valve. The cage was held stationary and the disc moved with the pulsatile pump. The diagram shows the Beall valve with the disc in open and closed positions. Trace 1 is from the anterior strut and is parallel to trace 3, the echo from the suture ring. Trace 2 is from the disc and moves up to trace 1 as the disc opens.
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Figure 2

Echocardiogram from a patient with a medium mitral Beall prosthesis. During ventricular systole the disc (trace 2) moves rapidly away from the anterior strut (trace 1), and during diastole the disc opens until it strikes the strut. Echo trace 3 arises from the suture ring.

the valve opens and closes. In figure 3 the horizontal axis represents time and the vertical axis represents distance. Velocity is recorded in cm/sec. Table 2 lists the average excursions measured by ultrasound of small Beall valves in nine patients. During each examination more than 15 separate measurements were made and the average excursion and standard deviation were calculated for each examination. The excursion and standard deviation for the entire group was obtained by averaging all individual measurements. The average excursion of a small Beall disc was calculated to be 0.56 cm with a standard deviation of 0.02 cm. As this technic of measuring disc excursion includes the width of the strut, the values are larger than the known small Beall excursion of 0.48 cm measured with a micrometer.*

*Micrometer measurements of disc excursion kindly supplied by Surgitool Incorporated, Pittsburgh, Pennsylvania.

Table 1

<table>
<thead>
<tr>
<th>Beall valve</th>
<th>Model no. 103</th>
<th>Model no. 104</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>0.56 ± 0.02</td>
<td>0.65 ± 0.02</td>
</tr>
<tr>
<td>Medium</td>
<td>0.67 ± 0.03</td>
<td>0.73 ± 0.02</td>
</tr>
<tr>
<td>Large</td>
<td>0.79 ± 0.01</td>
<td>-</td>
</tr>
</tbody>
</table>

Abbreviations: Ex = excursion.

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Table 2
Average Disc Excursion in Nine Patients with Small Beall Valves

<table>
<thead>
<tr>
<th>Pt</th>
<th>Average excursion ±1 SD (cm)</th>
<th>Examination</th>
<th>Individual measurements (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.56 ± 0.02</td>
<td>1st</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>0.57 ± 0.02</td>
<td>2nd</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>0.56 ± 0.02</td>
<td>1st</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>0.54 ± 0.03</td>
<td>2nd</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>0.57 ± 0.03</td>
<td>1st</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>0.60 ± 0.03</td>
<td>2nd</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>0.56 ± 0.02</td>
<td>1st</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>0.57 ± 0.04</td>
<td>1st</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>0.56 ± 0.01</td>
<td>1st</td>
<td>23</td>
</tr>
</tbody>
</table>

*Average excursion for group = 0.56 ± 0.02 cm.

Table 3 summarizes the average disc excursion measured by ultrasound in 19 patients with large, medium, or small Beall valves. Many of the patients were examined serially and at each examination 15-40 individual measurements of disc excursion were made. These valves were all inserted prior to May 1970.

The opening and closing velocities of these valves averaged 22 cm/sec and 40 cm/sec, respectively. There is much variability in the velocity of disc movement when comparing different patients and even when comparing velocities in the same patient at different times. Because cardiac output, stroke volume, heart rate, force of ventricular contraction, etc., could all affect disc velocity, opening and closing velocities were not correlated with ventricular function.

In May, 1970 occasional patients were examined in whom excursion of the disc was greater than expected from our average results for that size valve. When previous patients were reexamined the measurements continued to agree with those listed in table 3. After finding five patients with excursions larger than expected, it was realized that their valves had all been inserted after May of 1970. Table 4 lists the average disc excursion in five patients with small and medium Beall valves in this group. The average excursion for the small valve was 0.65 cm, which is 0.09 cm greater than the average excursion of small Beall valves inserted before May 1970. It was then found that the manufacturer had increased the excursions of the small valve by 0.06 cm to 0.1 cm and that the patients operated on after May 1970 had been given valves of the larger size (model no. 104). Similarly the average excursion of the new medium valve was 0.73 cm, which was 0.06 cm greater than the average excursion of medium Beall valves (model no. 103) listed in table 3. The manufacturer reported an increase of 0.05-0.08 cm in excursion of their new medium Beall valves over the old model.

The findings from three patients with malfunction of their mitral disc valves illustrate the importance of examining both struts and looking for abnormal motion patterns as well as decreased excursion.

Figure 4 is an echocardiogram from a patient (M.M.) with a size 7 Kay-Shiley mitral valve. Four years postoperatively the patient presented with mitral insufficiency, thromboembolic phenomena and a mean diastolic gradient of 35 mmHg across the valve. The excursion measured 0.62 cm which was within normal limits for this valve, and was obtained while examining the superior strut (fig. 4A). The excursion of the disc with respect to the inferior strut (fig. 4B) measured only 0.37 cm. This was a decrease of 40% in expected disc excursion. At operation a collar of fibrogranulomatous tissue was found to extend inward from the myocardium, and prevent proper seating of the disc.

A patient (J.F.) with mitral Beall valve dysfunction, diagnosed by ultrasound, is being reported separately. In this patient the disc echo did not merge with the superior strut echo, indicating incomplete opening of the valve. At operation, thrombus was found on the superior strut preventing complete opening of the disc.

Table 3
Average Disc Excursion in 19 Patients with Beall Valves Inserted before May 1970

<table>
<thead>
<tr>
<th>Beall model no. 103</th>
<th>Average excursion ±1 SD (cm)</th>
<th>Pts (no.)</th>
<th>Exams (no.)</th>
<th>Micrometer measurement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>0.56 ± 0.02</td>
<td>9</td>
<td>12</td>
<td>275</td>
</tr>
<tr>
<td>Medium</td>
<td>0.67 ± 0.03</td>
<td>9</td>
<td>14</td>
<td>280</td>
</tr>
<tr>
<td>Large</td>
<td>0.79 ± 0.01</td>
<td>1</td>
<td>4</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4
Average Disc Excursion in Five Patients with Beall Valves Inserted after May 1970

<table>
<thead>
<tr>
<th>Beall model no. 104</th>
<th>Average excursion ±1 SD (cm)</th>
<th>Pts (no.)</th>
<th>Exams (no.)</th>
<th>Micrometer measurement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>0.65 ± 0.02</td>
<td>2</td>
<td>5</td>
<td>230</td>
</tr>
<tr>
<td>Medium</td>
<td>0.73 ± 0.02</td>
<td>3</td>
<td>5</td>
<td>255</td>
</tr>
</tbody>
</table>
A third patient (T.M.) with a size 7 Kay-Shiley mitral prosthesis, had experienced severe thromboembolic complications and increasing symptoms of early congestive heart failure. Disc excursion, measured by ultrasound, decreased from 0.63 cm to 0.51 cm over 1 year. Figure 5 is a photograph of the valve removed at operation showing fibrous tissue overgrowing the ring and interfering with disc closure.

Discussion
The results of this study indicate that echocardiography is a reproducible and accurate technic for measuring prosthetic valve function. The reproducibility of this system can be estimated by comparing disc excursion measured on the same patient on repeated examinations (table 2). In most cases reproducibility is within 1 SD of the mean excursion for that patient.

The accuracy of echocardiography is best pointed out by the ability to discriminate between two models of a valve with an increase of only 0.06 cm in disc excursion. These differences were detected without prior knowledge of a change in design of the valves. Additional evidence of accuracy is that the standard deviation for all the examinations was less than 0.05 cm, which suggests that a change in disc movement of less than 1 mm may be accurately measured. This, however, does not mean that the resolving power of a 2.25 mHz transducer is better than 1 mm. Resolution is defined as the closest distance two objects can be brought together, and still be discerned as two objects, which is determined by the wave length of the sound energy, and thus, the frequency of the crystal. For a 2.25 mHz transducer, the limit of resolution is approximately 1 mm. This does not limit the accuracy with which the distance separating two objects greater than 1 mm apart can be measured. This is echo ranging, and can be called the accuracy of registration, and is apparently at least 0.06 cm.

It would be difficult to determine normal values for every type of prosthetic valve used, especially

Echocardiograms from a patient with mitral Kay-Shiley valve dysfunction. (A) The excursion of the disc at the superior strut measured 0.62 cm. (B) Disc excursion was only 0.37 cm at the inferior strut. At operation clot was found between the disc and suture ring in the area of the inferior strut.
with minor changes in excursion occurring with changes in valve designs. It is, therefore, important to obtain a baseline excursion and motion pattern for each patient in the immediate postoperative period. The patient can then be reexamined at regular intervals and changes in excursion or motion pattern noted.

The three cases of dysfunction demonstrate how useful ultrasound is in detecting malfunction and how accurate it can be in locating the position of a thrombus. A decrease in disc excursion indicates improper seating of the poppet and possible thrombus at the suture ring. Failure of the disc to open completely indicates thrombus or foreign matter on the strut. The importance of examining both struts cannot be overstated.

Dehiscence of the suture ring might be detectable if the valve cage changes in its motion pattern. Leakage around the suture ring, however, resulting in mitral regurgitation has been present without

Figure 5
Kay-Shiley prosthesis removed from patient T.M. after 5% years. Clot prevented proper seating of disc and an echocardiogram revealed decreased disc excursion.
causing any noticeable change in motion pattern or
disc excursion, as measured with ultrasound. Significant paraavalvular leak may possibly be
detected by increased stroke volume or cardiac output as measured by ultrasound.

More work is needed before opening and closing velocities can be correlated with ventricular function.

In summation: (1) An echocardiographic technic is described for measuring movements of prosthetic disc valves. (2) The method accurately measures disc movement to less than 1 mm, and has been used in 24 patients with normal valve function and three patients with valve dysfunction. (3) Echocardiography is a useful, noninvasive technic for accurate assessment of prosthetic mitral disc valve movement.

References
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Correction

JOHNSON ML, HOLMES JH, PATON BD: Circulation 47: 1274, 1973. On page 1276, figure 2 was printed backwards. Correct figure is reproduced above. First line of legend should read "Echocardiogram from a patient with medium mitral Beall prosthesis. During ventricular systole the disc".