mitral valve prolapse using this technique. Most importantly, there is no existing information regarding the two-dimensional echocardiographic-angiographic correlates observed in patients with mitral valve prolapse.

The purpose of this study was to compare the two-dimensional echocardiographic (2-D echo) appearance of mitral leaflet motion in patients with and without angiographically proven mitral valve prolapse. From this information, baseline descriptive criteria for the diagnosis of mitral valve prolapse by 2-D echo were formed.

Methods

Patients

One hundred eighty-three consecutive patients underwent complete clinical, 2-D echo, and angiographic examination in a three-month period for the diagnosis of various forms of heart disease. Of these, 49 patients were selected for this study on the basis of catheterization. These patients had either normal mitral valve function or mitral valve prolapse on cineangiogram and had 2-D echoes suitable for the analysis of mitral leaflet motion throughout the cardiac cycle. Twenty-eight patients were catheterized specifically for

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Supported in part by USPHS Grants HL 12715-07, HL 14228, HL 17670-01, and HS 01613. Dr. Gilbert is supported by the Canadian Heart Foundation.

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Received March 30, 1976; revision accepted June 7, 1976.
the diagnosis of angina-like chest pain. Selected clinical data
concerning reasons for catheterization, physical examination
and resultant hemodynamic data in these two groups of
patients are summarized in table 1. The patients were
divided into two groups. In group I, 15 patients, the results
of catheterization failed to reveal evidence for heart disease.
In group II, 34 patients, the results of catheterization
revealed unequivocal angiographic evidence of mitral valve
prolapse.

Catheterization Methods

All patients underwent complete left and right heart
catheterization using the Seldinger technique. Intracardiac
pressures were recorded in a standard fashion and cardiac
output was determined by the Fick method. Biplane left ven-
tricular cineangiograms were obtained with the patients in a
slight right anterior oblique position using a mixture of 66%
meglumine diatrizoate and 10% sodium diatrizoate (Ren-
ograin-76). Selective coronary cinearteriography was per-
formed in all patients. Significant coronary artery disease
was defined as a 75% or greater stenosis of one or more ma-
jor coronary vessels. Left ventricular cineangiograms were
independently analyzed for evidence of mitral prolapse7-11
and the presence and severity of mitral regurgitation. Mitral
prolapse was noted when one or both of the mitral leaflets
was seen moving into the left atrium in systole in both right
anteriorterior and left anterior oblique views. The results of
angiography were agreed upon by two angiographers.

Echocardiographic Methods

Two-dimensional echoes were obtained using a previously
described12-13 real-time, phased array imaging system de-
veloped in the Duke University Biomedical Engineering De-
partment that is currently undergoing clinical evaluation in
the Duke University Department of Medicine. This imaging
system uses a hand-held, 24 element 2.25 MHz transducer
array that measures 14 × 24 mm at the site of skin contact
and relies upon phased array principles to electronically
steer the sound beam through the structures under investiga-
tion. Real-time cross-sectional images of cardiac structures
are presented in a circular sector format, 50, 60, or 90
degrees in azimuth. Images are permanently recorded on
videotape for later playback and analysis.

Figure 1 schematically shows the plane of view used for
examination of the long axis of the mitral valve and left venticle.
This view was obtained using previously described

techniques.13 Note that the plane of the sector arc ideally in-
tercepts the aortic root, left atrium, long axis of the mitral
valve and left ventricle. A systolic single-frame photograph
and schematic illustration of a normal mitral valve are
shown in figure 2.

It is important to note that the single-frame images of the
videotape recordings were made by means of a 35 mm
photograph of the sector arc in a stop-frame mode. As such,
there is a loss of visual integration of motion that normally
accompanies real-time playback. Moreover, during stop-
frame mode, there is a severe degradation in image quality
caused by photographing a single field of a complete video-
tape frame which consists of two interlaced fields. For ex-
ample, an individual videotape recording frame represents
the scan information collected in only 1/60 of a second. When
operating in the 90-degree, 160-line format, therefore, each

---

**Table 1. Summary of Clinical Data**

<table>
<thead>
<tr>
<th></th>
<th>Group I Normal</th>
<th>Group I Mitral prolapse</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patients</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>44 ± 8</td>
<td>47 ± 15</td>
</tr>
<tr>
<td>Male:female</td>
<td>7:8</td>
<td>19:15</td>
</tr>
<tr>
<td><strong>Reason for catheterization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest pain</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Syncope</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shortness of breath</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td><strong>Physical examination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic click alone</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Systolic murmur alone</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Systolic click and murmur</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td><strong>Catheterization data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEDP (mm Hg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>10 ± 3</td>
<td>10 ± 5</td>
</tr>
<tr>
<td>Range (4 - 15)</td>
<td>(4 - 15)</td>
<td>(4 - 15)</td>
</tr>
<tr>
<td>Cardiac index (L/min/m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>3.2 ± 0.9</td>
<td>3.1 ± 0.5</td>
</tr>
<tr>
<td>Range (2.3 - 4.0)</td>
<td>(1.3 - 5.7)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: LVEDP = left ventricular end-diastolic pressure.
single frame video field represents only one-half (80 lines) the information provided in the actual scan or in real-time playback.

All echoes were obtained within one day of cardiac catheterization. The 2-D echo appearance of the mitral valve leaflets, the systolic mitral ring motion and the adjacent left ventricular wall movement were analyzed. In addition, quantitative assessment of the point of early systolic coaptation of the mitral leaflets was obtained by measuring the distance from the anterior echo of the posterior aortic root at its junction with the mitral leaflet (mitral ring) to the point of leaflet coaptation (fig. 3). The point of anterior measurement moved with the aortic root rather than the mitral leaflet. Discrete echoes from the anterior surface of the anterior mitral leaflet were often obscured by multiple echoes due to leaflet curvature of chordal structures. The point of initial leaflet coaptation was, therefore, chosen as the position for posterior measurement since it could be most easily identified. This calculated index is notably similar to that previously used by Johnson in time-motion echocardiography.

Time-motion echocardiograms were obtained in most patients (37 of 49) using previously described techniques. Particular care was taken to assess mitral leaflet systolic contour with the transducer positioned perpendicularly on the chest wall according to the method of Markiewicz. Echocardiographic sweeps were performed with the transducer initially held perpendicular to the mitral leaflets and then angled superiority to the aortic root. Measurement of posterior leaflet coaptation was made from the posterior aortic root wall to the point of the leaflet coaptation in early systole. The presence or absence of mitral prolapse was determined using previously published criteria. Thirty of the time-motion examinations were performed using a commercially available M-mode ultrasonoscope while the remaining seven had this examination performed simultaneously with the 2-D echo using the recently added line selectable M-mode feature of the cross-sectional scanning system.

Results

Group I

Two-dimensional ultrasound showed that in diastole the anterior leaflet of the mitral valve opened downward and anteriorly, while the posterior mitral leaflet moved against the posterior left ventricular wall. With the onset of systole, the anterior leaflet moved posteriorly and the posterior leaflet moved anteriorly, coapting and creating a funneled appearance (fig. 2). Through systole, both leaflets arched slightly toward each other and the entire mitral apparatus descended in an anterior inferior direction. Slight posterior curvature of the anterior mitral leaflet during systole was quite normal. During systole, there was never a superior movement of the leaflets above the level of the atroventricular ring (fig. 3). Reliable measurements of the point of leaflet coaptation behind the posterior aortic root wall could be made in 12 of the 15 patients and averaged 0.5 ± 0.2 cm (range 0.2 to 0.7 cm). Since the degree of posterior coaptation was minimal in these patients, there was only slight angulation noted between the posterior aortic root and anterior mitral leaflet in systole (fig. 2 — arrow). In addition, the posterior mitral ring and its adjacent left ventricular wall moved anteriorly and downward in systole in synchrony with the remainder of the left ventricle. In all patients, left atrial size was normal (less than 4 cm).
Group II

No patient had angiographic evidence of significant coronary artery disease. Seventeen patients had severe mitral insufficiency by cineangiography, four had mild mitral insufficiency, and in 13 patients there was no mitral insufficiency. Twenty-three patients had angiographic evidence of combined anterior and posterior mitral leaflet prolapse, while 11 patients had angiographic evidence of prolapse of the posterior leaflet alone. No instance of isolated prolapse of the anterior mitral leaflet was seen.

Two-dimensional echocardiography demonstrated excessive posterior closure of the coaptation point of the mitral leaflets (mean ± SD, 1.4 ± .05 cm, range 0.6 to 2.4) (fig. 4) as the most common finding (table 2). Only one patient had a closure point less than 0.8 cm behind the posterior aortic wall. The displaced posterior closure resulted in an accentuation of the angle formed by the posterior aortic root and the anterior mitral leaflet in systole (fig. 4B — arrow). Superior arching of the anterior and/or posterior mitral leaflets above the level of the mitral ring (figs. 5 and 6) was considered positive evidence of mitral leaflet prolapse. Twenty-four patients had unusual systolic curling of the posterior mitral ring on the adjacent myocardium. In normals, the posterior mitral ring moves downward and anteriorly in systole. In those patients with mitral prolapse and ring curling, the systolic movement of the ring was primarily downward with little, if any, anterior motion, thus resulting in a curled appearance when visualized in real-time playback. The left atrium was dilated in ten patients (greater than 4 cm).

When superior systolic movement of either mitral leaflet above the level of the mitral ring was severe, that leaflet appeared rather large and manifested a whip-like motion during early diastole as the leaflet opened. This exaggerated excursion of the mitral leaflet is illustrated in figure 7. The rapid change of position of the anterior mitral leaflet (panels C and D) from its position 1/30 second earlier (panels A and B) is shown.

The results of standard M-mode echocardiography are summarized in table 3. Most importantly, there were seven patients in group II without detectable M-mode evidence for mitral prolapse using currently accepted criteria. Four of

![Figure 4](image4.png)

**Figure 4.** Panel A shows a systolic frame through the long axis of the left ventricle in a patient with angiographically proven prolapse of the mitral valve. Note the excessive coaptation of the anterior and posterior mitral leaflets and the decreased (more acute) angle between the atrial surface of the anterior mitral leaflet and the posterior aortic root wall. Panel B is the schematic illustration of panel A.

![Figure 5](image5.png)

**Figure 5.** Scan of a patient displaying excessive superior movement of the anterior mitral leaflet above the plane of the atrioventricular ring. Panel B is a schematic illustration of panel A.
Figure 6. Panel A shows a systolic frame displaying excessive superior movement of the posterior mitral leaflet above the level of the mitral valve ring. Panels C and E represent the left anterior oblique (LAO) and right anterior oblique (RAO) angiographic views of the posterior leaflet prolapse. Panels B, D, and F are schematic representations of panels A, C, and E, respectively. AA = aortic annulus; MA = mitral annulus; PLP = posterior leaflet prolapse.

Figure 7. Panels A and C show diastolic scans two frames apart (1/30 second) illustrating the rapid whipping motion of the mitral leaflets in early diastole. Panels B and D are schematic illustrations of panels A and C, respectively.
these patients had M-mode examinations performed where multiple areas of the mitral leaflets were examined using the simultaneous M-mode feature of the cross-sectional imaging system. Of the 37 patients with M-mode examinations, 26 (all in group II) did show M-mode echocardiographic evidence for displaced posterior closure of the mitral valve in systole.

### Echocardiographic-Angiographic Correlations

The 2-D echo-angiographic correlations regarding the specific leaflet involved in the mitral prolapse are summarized in table 4. All 34 patients in group II had 2-D echo evidence of mitral prolapse. It is important to note that 2-D echo suggested additional prolapse of the anterior mitral leaflet in nine of the eleven patients with angiographic evidence for posterior prolapse alone. In only one case did the 2-D echo fail to identify angiographic prolapse of the posterior mitral leaflet.

In general, when posterior mitral leaflet prolapse was judged severe by angiogram, a significant superior systolic arching of the posterior leaflet was seen on 2-D echo (fig. 6). When posterior leaflet arching was less severe on angiography, minimal or no superior motion was seen on 2-D echo and systolic curling of the posterior mitral ring on the posterior myocardium was the only sign suggesting posterior mitral leaflet prolapse. Similarly, when anterior mitral leaflet prolapse was judged severe by angiogram, superior systolic arching of the anterior mitral leaflet was significant on 2-D echo (fig. 5). It is important to note, however, that minor degrees of arching of the anterior mitral leaflet above the level of the mitral ring were seen in nine patients without angiographic evidence of anterior mitral leaflet prolapse.

In the four patients with mild mitral regurgitation by angiography, both the anterior and posterior mitral leaflets were seen to prolapse by both techniques. Similarly, 13 of the 17 patients with severe mitral regurgitation by angiography had anterior and posterior leaflet prolapse demonstrated by angiography and 2-D echo. Three of the remaining four patients showed isolated posterior leaflet prolapse by angiography but combined leaflet prolapse by 2-D echo. One patient showed prolapse of both leaflets by angiography but only posterior leaflet prolapse by 2-D echo. All ten patients with left atrial dilatation by 2-D echo had severe angiographic mitral regurgitation. While quantitative data were not available on all patients, left ventricular wall motion was assessed in qualitative terms by Gorlin’s criteria and no abnormalities were seen by either cineangiography or 2-D echo.

### Discussion

Mitral prolapse is a relatively common cardiac valvular abnormality. Since the initial descriptions of the time-motion echocardiographic appearance of mitral prolapse by Shah and Dillon, this technique has become a useful method for the noninvasive detection of patients with this entity. As clinical experience has grown, however, several authors have demonstrated limitations in the specificity of time-motion echocardiography for the diagnosis of this disorder. Weyman, Henry, and Kisslo and others have demonstrated the initial applications of cross-sectional echocardiography for the detection of a variety of cardiac disorders. Although Sahni has recently reported real-time, cross-sectional echocardiographic data in children with mitral prolapse, there are no reports of two-dimensional echocardiographic and angiographic correlations in patients with this entity.

It should be noted that there are several limitations to this study. First, no attempt has been made to test either the sensitivity or the specificity of two-dimensional echocardiography in detecting mitral prolapse. It is possible that patients with angiographically undetectable mitral prolapse were included in group I. The results of this study simply serve to describe certain common features in the 2-D echo characteristics of mitral leaflet motion in normal patients and in those with angiographically proven mitral valve prolapse. Second, in patients with prolapse examined in this study, the prolapse was most often severe. Of the 34 patients with prolapse, 17 had severe mitral insufficiency. This population was, of course, highly selected, as it is based solely on catheterized patients. It is important to recognize, however, that in the 13 patients with mild or moderate prolapse and no angiographic evidence for mitral insufficiency, 2-D echo evidence for displaced posterior closure, systolic superior leaflet motion, or curling of the posterior mitral ring were still present. Third, 2-D echo, like all pulsed ultrasonic techniques, is somewhat limited in its applicability to all patients due to poor sound transmission characteristics induced by abnormal chest wall configuration, patient age, or the presence of interposed lung. Clinical experience with real-time, two-dimensional echocardiography in this laboratory in nearly 1,000 consecutive, unselected patients has revealed that an unsatisfactory 2-D echo of the mitral leaflets is obtained in approximately 10% of examinations. Fourth, correlative M-mode and 2-D echo data were available in only 37 of the 49 patients in this study (table 3). All patients in group I examined by standard M-mode technique were completely normal. Of interest is the fact that seven patients in group II also failed to show M-mode evidence of prolapse by currently accepted criteria. There was no obvious relationship between the morphology of mitral prolapse seen on either 2-D echo or angiography and abnormalities noted on M-mode. Twenty-six of the twenty-nine patients in group II, however, did show evidence for displaced posterior coaptation in systole.

#### Table 3. Results of M-mode Echocardiography

<table>
<thead>
<tr>
<th>Group</th>
<th>Normal</th>
<th>Pansystolic</th>
<th>Late systolic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Group II</td>
<td>7</td>
<td>8</td>
<td>14</td>
<td>29</td>
</tr>
</tbody>
</table>

#### Table 4. Angiographic and Two-dimensional Echocardiographic Correlation of Mitral Prolapse

<table>
<thead>
<tr>
<th>Prolapse by angiography</th>
<th>Anterior and posterior leaflets (N = 23)</th>
<th>Posterior leaflet (N = 11)</th>
<th>Anterior leaflet (N = 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolapse by echo</td>
<td>Anterior and posterior leaflets</td>
<td>Posterior leaflet</td>
<td>Anterior leaflet</td>
</tr>
<tr>
<td></td>
<td>(N = 23)</td>
<td>(N = 11)</td>
<td>(N = 0)</td>
</tr>
<tr>
<td>Anterior and posterior</td>
<td>21</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>posterior leaflets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior leaflet</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Anterior leaflet</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Although the numbers are still relatively small, these findings may suggest that 2-D echo is more sensitive than M-mode in detecting mitral prolapse when criteria concerning mitral systolic contour alone are used. Further studies seeking to define the interrelationships of 2-D echo and M-mode are presently underway.

The most common 2-D echo feature (table 2) of mitral prolapse was displaced posterior coaptation of the mitral leaflets 0.8 cm or greater beyond the posterior aortic root (fig. 4). In the case of anterior leaflet prolapse, when the leaflet is large and redundant, this possibly occurs about secondary to excess leaflet tissue. With posterior mitral leaflet prolapse, this abnormality is likely brought about as a result of the superior motion of the posterior leaflet, drawing the anterior leaflet markedly posteriorly in early systole. It should be understood that the measurement of displaced posterior coaptation of the mitral leaflets in patients with mitral prolapse should not be used to differentiate patients with normal valve motion from those with prolapse. Rather, this quantitative index was applied in this study purely to provide a means for expressing the markedly disordered valve closure seen in these patients. Unfortunately, the reliability of any echocardiographic measurement is limited by resolution, gain setting, and/or other factors that affect the quality of the ultrasonic image. The ultimate utility of this measurement remains to be proven by prospective investigations in larger series of patients.

The most reliable indicator of mitral prolapse should remain superior motion of either one or both mitral leaflets above the level of the mitral ring in systole. When angiographic prolapse is severe, this 2-D echo finding will also be severe and the involved leaflet will appear large and redundant. Also with severe prolapse, during early diastole, as the leaflets first move downward into the ventricle, a whip-like motion is present (fig. 7) near the tip of the involved leaflet.

When the degree of angiographic anterior prolapse is minor, superior motion of the anterior mitral leaflet is usually seen on 2-D echo. In fact, superior arching of the anterior mitral leaflet by 2-D echo suggesting anterior mitral leaflet prolapse appears more common than is evident by angiography. In this study, nine patients had anterior mitral leaflet prolapse by 2-D echo that was not seen by angiography. One must keep in mind the normal anatomy of the mitral valve as described by Ranganathan et al.28 Because the anterior mitral leaflet has greater height than the posterior leaflet, it is more easily seen by 2-D echo. Despite this disparity in height, however, the anterior leaflet is frequently difficult to define by angiography due to the fact that it is superimposed on the opacified silhouettes of the left ventricle. On the other hand, the posterior leaflet has a wider attachment to the atrioventricular ring than the anterior leaflet, and this, coupled with the fact that it is viewed in profile in the left anterior oblique position, renders it easily visible by angiography. DeMaria et al. and others have previously pointed out some of the problems in assessing mitral valve prolapse with cineangiography.

When angiographic posterior prolapse is minor, superior motion of the posterior leaflet is either minimal or not evident and one must rely on the abnormal curling of the mitral ring on the adjacent posterior myocardium before prolapse can be suggested by two-dimensional echo. Curling, as defined in this study, relates to abnormal annulus motion in an inferior direction relative to its adjacent myocardium. It is important to note that this curling motion can only be appreciated when the cross-sectional echocardiograms are played in real-time. The specific etiology of this visually apparent curling remains uncertain since we did not visualize left ventricular wall motion abnormalities by 2-D echo or by angiography, as have been previously reported by other authors.26-38

Although it was not possible to identify specific scallops of the posterior mitral leaflet by 2-D echo, it was possible to identify localized differences in the manifestations of mitral prolapse. The arrows in figure 1 demonstrate the rotational movements of the heart through the 2-D echo plane that occurs with the cardiac cycle. Thus, it is possible that portions of the mitral valve visualized in early systole may rotate out of the plane of view in mid or late systole. Correct 2-D echo technique is therefore important for the determination of mitral prolapse, as small angulations in transducer position may result in markedly differing appearances of the mitral apparatus. For example, slight lateral angulation of the transducer may show only minor posterior prolapse. As the

![Diagram](image-url)
transducer is then swept medially across the valve structures, the displaced posterior coaptation and severe anterior and posterior prolapse become evident. Figure 8 illustrates the multiple patterns of mitral prolapse that may be seen by two-dimensional echo and points out that one or more patterns may be evident in any one patient. It is recommended that the entire mitral valve be carefully examined by sweeping the 2-D echo plane laterally to medially so that all abnormalities may be detected.

It should, however, be noted that if the transducer is angled medially and tangentially across the mitral orifice in normals, false posterior coaptation and minor superior arching of the anterior mitral leaflet may result. In this case, the anterior-posterior diameter of the mitral ring appears narrow and posterior leaflet motion remains normal.

In conclusion, in patients with angiographically demonstrated mitral valve prolapse, it appears that certain abnormalities of mitral valve motion are evident by two-dimensional echocardiography; 1) posteriorly displaced leaflet coaptation, 2) systolic movement of one or both mitral leaflets above the level of the mitral ring, and 3) systolic curling motion of the posterior mitral ring on its adjacent myocardium. One or more of these abnormalities was found in all 34 patients with mitral valve prolapse examined in this study. Future application of this new ultrasonic imaging technique, however, will depend upon further study of the sensitivity and specificity of these criteria in large numbers of patients with suspected mitral prolapse syndrome.

Acknowledgment

The authors wish to thank Mrs. Robyn Haney and Mrs. Elaine Veazey for their assistance in the preparation of this manuscript.

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B W Gilbert, R A Schatz, O T VonRamm, V S Behar and J A Kisslo

Circulation. 1976;54:716-723
doi: 10.1161/01.CIR.54.5.716
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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