Size and Motion of the Mitral Valve Annulus in Man

II. Abnormalities in Mitral Valve Prolapse

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SUMMARY Changes in mitral annular areas and cyclic area changes were measured in 17 patients with mitral valve prolapse (MVP) and compared with those in 12 normal subjects. Using wide-angle, phased-array, two-dimensional echocardiography, mitral valve annular attachments were recorded in a view close to the apical four-chamber view, then at 30° rotational intervals around the circumference of the annulus. Diameters and chords from planes at 30° rotational intervals were used to reconstruct the annulus at selected times during the cardiac cycle. Annular areas were measured by planimetry, corrected for body surface area and expressed as area index. In normal subjects, the maximal mitral annular area index was 3.9 ± 0.7 cm²/m² (mean ± SD). Of 11 MVP patients with minimal mitral regurgitation (MR), five had a dilated annulus (5.8 ± 0.3 cm²/m², p < 0.001) and six had a normal-sized annulus (4.2 ± 0.5 cm²/m²). In six MVP patients with at least moderate MR, annular dilatation was marked (area index 8.5 ± 1.4 cm²/m², p < 0.001) and systolic annular area reduction (16 ± 5%) was less than in normal subjects (27 ± 3%, p < 0.001). Cyclic annular area changes in MVP patients with minimal MR were similar to those in normal subjects.

Mitrail annular size in patients with MVP ranges from normal to markedly dilated. The occurrence of mitral annular dilatation in MVP patients with minimal MR indicates primary or intrinsic annular dilatation rather than annular dilatation secondary to left atrial or left ventricular enlargement. Patients with MVP and significant MR had marked annular dilatation and less-than-normal systolic annular area reduction.

ABNORMALITIES of mitral annular size in some subjects with mitral valve prolapse (MVP) have been reported at autopsy.1,2 suggested by angiographic study3 and found at operation.2,4-6 Although the function of the mitral annulus in MVP has not been examined previously, abnormal contraction of the left ventricular inflow tract has been demonstrated angiographically.7,8 The abnormal motion of the posterior mitral valve annulus shown by two-dimensional echocardiography in some patients with MVP1 suggests that annular annular function might be abnormal in some patients with MVP.

Our understanding of a role of the mitral annulus in MVP has been hampered by lack of a method to study size and function of the mitral annulus in intact man. We therefore investigated mitral annular size and cyclic area changes using our recently described two-dimensional echocardiographic technique9 in patients with MVP and in normal subjects.

Materials and Methods

Echocardiographic Criteria for MVP

M-mode echocardiograms showing posterior buckling of mitral valve leaflets in mid-systole were considered diagnostic of MVP.10,11 In patients with pansystolic mitral leaflet bowing on M-mode echocardiograms, the diagnosis of MVP was accepted only if there was strong support from two-dimensional echocardiography or angiography. Superior arching, seen on two-dimensional echocardiography, of one or both mitral leaflets above the plane of the mitral annulus was considered positive evidence of MVP.9 Apical two-dimensional echocardiographic views were particularly useful in the diagnosis of MVP.12

Patients

Of 24 patients with echocardiographic features of MVP examined over an 8-month period, 17 were included in this study on the bases of good-quality apical two-dimensional echocardiograms and the absence of mitral annular calcification. In all subjects with MVP, systolic superior arching of one or both mitral valve leaflets above the plane of the mitral annulus was shown by two-dimensional echocardiography. There were 16 males and one female. All were in sinus rhythm. Eleven subjects had minimal mitral regurgitation (MR) and six had at least moderate MR. The 11 subjects with minimal MR had a mid-systolic click or a soft (grade 1/6 or 2/6) late systolic murmur, mid-systolic prolapse and normal left atrial and left ventricular cavity dimensions by M-mode echocardiography, and normal heart size on the chest x-ray. In contrast, the six subjects with at least moderate MR had pansystolic murmurs without clicks, pansystolic prolapse (2 mm) and dilated left atrial (42 mm)
and left ventricular (> 54 mm) chambers by M-mode echocardiography and cardiac enlargement radiologically. Left ventricular angiograms in the right anterior oblique projection in four of these six patients confirmed MVP and severe MR. The angiographic diagnosis of MVP was made by visual analysis of one or more scallops protruding or prolapsing into the left atrium in systole.

The control group consisted of 12 normal male subjects in whom high-quality apical echocardiograms were obtained.

Morphologic characteristics of Marfan's syndrome were not present in any subject.

Two-dimensional Echocardiography

Subjects were studied in the left lateral decubitus position. A wide-angle phased-array system (Varian 3000) was used to perform two-dimensional echocardiography. Studies were recorded on half-inch videotape using a Sanyo cassette recorder. The images could be redisplayed in real time, slow motion or as single frames. Still frames were recorded on 90-mm film during real-time studies and are used as illustrations in this report. Mounted on the echocardiographic transducer was an inclinometer, which has a circular fluid-filled chamber containing an air bubble to allow measurement of 30° transducer rotational intervals.

We have described in detail our method of reconstructing the mitral valve annulus at 12 times during the cardiac cycle from diameters and chords measured at 30° rotational intervals. Briefly, the transducer was held at the left ventricular apical impulse with the beam directed toward the left atrium and the mitral valve leaflets to identify their annular hinge points. A view close to the standard apical four-chamber view was usually the initial plane of examination. At this rotation the transducer was angled back and forth in an arc perpendicular to the plane of the beam to identify the maximal orifice diameter in early diastole just before the mitral valve leaflets opened. During held expiration, about 10 cardiac cycles were recorded on videotape. The transducer was then rotated 30° clockwise, the widest annular diameter at this rotation was identified and recordings were made. Figure 1 is a composite of still frames taken in late diastole in a subject with MVP from planes at 30° rotational intervals.

The center of the mitral annulus just before the leaflets opened in early diastole when the annulus was considered nearly elliptical was used as a reference point. A reference line drawn on a strip of clear plastic was taped to the video monitor screen so that it passed from the left ventricular apex and through the reference point; that is, it bisected the annular diameter in early diastole just before leaflet opening. After advancing the videotape to selected times during the cardiac cycle, annular diameters and distances moved from the reference line were marked on an overlaid sheet of clear plastic. The measured diameters (or chords) from each plane were placed at their measured correct position relative to the reference point to reconstruct the annulus at 12 selected times during the cardiac cycle. Reconstructed annular areas were measured with a planimeter, corrected for body surface area and expressed as annular area index. Circumferences were measured with a wheel.

M-mode Echocardiography

M-mode output of the phased-array system was recorded on a Honeywell 1226 pressor. Left ventricular internal dimension at end-diastole (LVIDd) was

Figure 1. A composite of late diastolic still frames taken at 30° rotational intervals in a subject with mitral valve prolapse. In panel A, the two-dimensional echocardiographic beam sliced the annulus at 11 and 5 o'clock (o'clock) as indicated, in panel B after 30° clockwise rotation at 12 and 6 o'clock, and so on. Black arrows indicate mitral leaflet annular hinge points. White arrow indicates aortic valve (AO). LV = left ventricle; LA = left atrium; RV = right ventricle.
measured at chordal level and timed at the onset of the QRS. Maximal left atrial dimension was measured from the leading edge of the posterior aortic wall echo to the leading edge of the posterior left atrial wall echo.

**Data Analysis**

Data are summarized in the tables and text as mean ± SD or as mean and range. Where mean data are graphed, the standard error of the mean is given along with the number in each group. To test the hypothesis that no difference existed between means of groups, one-way analysis of variance was used. If the hypothesis was rejected at the 5% level, two-sided \( t \) tests were used to determine the location and significance of differences. No more than five \( t \) tests were used after each analysis of variance and a difference between means was considered to be present if the hypothesis that no difference existed was rejected by the \( t \) test at the 1% level or less.

**Results**

Patients with MVP were separated into three groups based on mitral annular size and degree of MR: group 1 (\( n = 6 \)) — minimal MR and normal annular size; group 2 (\( n = 5 \)) — minimal MR and a dilated annulus; group 3 (\( n = 6 \)) — moderate or severe MR and a dilated mitral annulus. An annulus was considered enlarged if it was more than 2 standard deviations larger than mean normal. The mitral annular area index and changes during the cardiac cycle in normal subjects and in MVP groups 1, 2 and 3 are shown in figure 2. The annular area index is the annular area corrected for body surface area. The maximal annular area index (fig. 3) in MVP group 1 patients (4.2 ± 0.5 cm²/m²; mean ± SD) was not different from that in normal subjects (3.9 ± 0.7 cm²/m²). The maximal area index in MVP group 2 (5.8 ± 0.3 cm²/m²) was larger than that in group 1 (\( p < 0.005 \)). The maximal area index in MVP group 3 (8.5 ± 1.4 cm²/m²) was larger than that in group 2 (\( p < 0.01 \)).

In normal subjects, the mitral valve annulus size increased during diastole to a maximum at the time of the electrocardiographic p wave (fig. 2). There was then annular narrowing, most of which was presystolic and preceded any change in left ventricular volume. Minimal size in the second quarter of systole was followed by annular enlargement before the end of systole. The mean percent reduction in area, calculated as ([maximal diastolic area – minimal systolic area] / maximal diastolic area) was 27 ± 3% in normal subjects. The mean percent annular area reduction (fig. 4) in MVP group 1 (25 ± 6%) and MVP group 2 (27 ± 5%) was not different from normal, but area reduction in MVP group 3 (16 ± 5%) was less than that in normal subjects (\( p < 0.001 \)).
Patients with MVP in groups 1 and 2 were similar (table 1) with respect to age, absence of dyspnea, auscultatory findings of midsystolic click or late systolic murmur, and presence of midsystolic prolapse and normal left ventricular and left atrial dimensions by M-mode echocardiography. In contrast, patients with MVP in group 3 (table 1) had greater symptomatic limitation, pansystolic murmurs on auscultation, pansystolic prolapse and dilated left-heart chambers by M-mode echocardiography.

The MVP patients were also subgrouped based on auscultatory findings and the degree of MR by clinical and angiographic assessment: group A (n = 5) — click only and no MR; group B (n = 6) — click and/or late systolic murmur with minimal MR; group C (n = 6) — systolic murmurs and moderate or severe MR (table 2). This classification allowed separate analysis of patients who had a click only. Patients in groups A and B had normal left ventricular end-diastolic diameter and left atrial dimension by M-mode echocardiography. Three of five patients in group A and two of six in group B had a maximal annular area index greater than 2 standard deviations from the normal mean value. All group C patients had a dilated annulus and enlarged left ventricular and left atrial dimensions.

**Discussion**

MVP is common, with a prevalence rate of about 5%. It represents a wide spectrum of disorders, ranging from asymptomatic prolapse to severe holo-systolic MR. Heterogeneity in MVP is supported by our finding of dissimilarities in mitral annular size and function.

Surgical and necropsy series show dilatation of the mitral annulus in patients with significant
MR. In our study, annular circumferences measured echocardiographically in normal subjects were similar to those in the necropsy series (table 3). In patients with MVP and significant MR, annular dilatation was 67% and 47% in the two necropsy series\(^1\),\(^2\) (table 3). In our echocardiographic study of MVP patients with significant MR, mean maximal diastolic circumference was 53% larger than normal and mean minimal systolic circumference was 63% larger than normal.

There is little information available on mitral annular size in patients with MVP and minimal MR because few come to cardiac catheterization, surgery or necropsy. The annulus was not dilated at necropsy in five patients with systolic click or systolic click and middle to late systolic murmur.\(^23\) However, in five patients with MVP and minimal MR, the annulus was dilated at surgery.\(^6\) In seven patients studied angiographically, an increased annular diameter was found in association with mild or trivial MR.\(^3\) We report six subjects with MVP and minimal or no MR in whom the mitral annulus, measured echocardiographically, was normal in size, and five in whom it was dilated. The normal left atrial and left ventricular cavity sizes in these MVP subjects with a dilated annulus argue for primary or intrinsic annular dilatation rather than annular dilatation secondary to left atrial or left ventricular enlargement.

The prognosis for patients with MVP and mild MR is very good,\(^23\)-\(^28\) but a few patients progress to more severe regurgitation.\(^24\),\(^27\)-\(^29\) It is not clear how frequently progression to more severe MR occurs, and there is no method to identify those at risk of progression. The MVP patients who have dilated annuli despite only trivial MR might be at greater risk of progression than those with normal annular size. The mitral valve can maintain reasonable structural and functional integrity as long as the two leaflets have a broad area of systolic apposition and can be maintained in an ideal subannular position within the ventricle during systole.\(^32\) Reduction of this area of systolic apposition, one cause of which is annular dilatation, exposes leaflets and chordae to increased stresses.\(^32\)\(^33\) The prolapsing leaflet behaves as an unfurled sail, catching the "wind" of ventricular systole and subjecting itself, its supporting chordae, papillary muscle and the underlying ventricular wall to abnormal and destructive stress.\(^32\)\(^33\) Long-term follow-up studies using our two-dimensional echocardiographic technique would be necessary to determine whether MVP patients with a dilated annulus and trivial MR are more likely to have progression of MR than those without annular dilatation.

In the present study, the mitral annulus in normal subjects increased in size after mitral valve opening to a maximal size in late diastole. The annulus narrowed with atrial contraction, and reached its minimal size during the second quarter of systole. Most of the annular narrowing was presystolic and preceded any change in left ventricular volume. The annulus began to widen in the latter half of systole. These results are similar to those in radiographic studies in dogs with lead markers sutured to the mitral annulus.\(^34\)\(^35\)

Abnormal mitral annular function in some MVP patients can be suggested by abnormal left ventricular inflow tract contraction demonstrated angio-

**Table 2. Patient Subgroups on Basis of Auscultatory Findings and Degree of Mitral Regurgitation**

<table>
<thead>
<tr>
<th>Auscultation</th>
<th>Group A (n = 6)</th>
<th>Group B (n = 6)</th>
<th>Group C (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Click only</td>
<td>Click and LSM or LSM or PSM</td>
<td></td>
</tr>
<tr>
<td>Timing of prolapse by M-mode</td>
<td>Midsystolic</td>
<td>Midsystolic</td>
<td>Pansystolic</td>
</tr>
<tr>
<td>LVIDa (mm) (mean ± sd)</td>
<td>49 ± 3</td>
<td>50 ± 3</td>
<td>62 ± 7</td>
</tr>
<tr>
<td>LA (mm) (mean ± sd)</td>
<td>35 ± 4</td>
<td>35 ± 5</td>
<td>51 ± 8</td>
</tr>
<tr>
<td>Maximal annular area index (cm²/m²)</td>
<td>5.1 ± 0.9</td>
<td>4.8 ± 1.0</td>
<td>8.5 ± 1.4</td>
</tr>
<tr>
<td>(normal = 3.9 ± 0.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. with annulus greater than 2</td>
<td>3/5</td>
<td>2/6</td>
<td>6/6</td>
</tr>
<tr>
<td>mean</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: LSM = late systolic murmur; PSM = pansystolic murmur; LVIDa = left ventricular internal dimension at end-diastole.
graphically. The demonstration by two-dimensional echocardiography of abnormal motion of the posterior mitral valve annulus in some patients with MVP suggests abnormal mitral annular contraction. In our MVP patients with minimal MR, the changes in annular size during the cardiac cycle were normal. However, in our MVP patients with at least moderate MR, all of whom had a dilated annulus, the percent annular area reduction was reduced. Defective systolic contraction of the mitral annulus aggravates the effect of intrinsic annular dilatation. The mitral valve apparatus may be exposed to increased stresses during systole, which may predispose to progression of prolapse and mitral regurgitation.

In conclusion, patients with MVP and minimal or no MR fall into two categories — those with a normal-sized annulus and those with a dilated annulus. The significance of these categories is not clear. Further studies are required to determine whether patients with a dilated annulus are at risk of progression of MR. We conclude that mitral annular dilatation can occur as a primary pathology and that the development of significant MR is associated with further dilatation. Cyclic changes in mitral annular size in patients with minimal MR were normal, but patients with significant MR had not only annular dilatation, but also a less-than-normal reduction in systolic annular area.

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Echocardiographic Detection of Left Main Coronary Artery Obstruction

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SUMMARY Advances in two-dimensional echocardiography have improved the prospects of using this technique to detect left main coronary artery (LMCA) obstruction. Using an echocardiograph that had digital gray scale, a 3-MHz transducer and strobe freeze-frame capability and reviewing recordings on an off-line videotape-vidiodisc analyzer, we retrospectively examined the LMCA in 72 patients who underwent coronary cineangiography. Angiography showed 50% or greater LMCA obstruction in seven patients. All seven had high-intensity echoes in the walls of the LMCA. The high-intensity echoes were irregularly located in the artery and partially occluded it. The LMCA could frequently be recorded proximal and distal to the obstruction. A blinded observer reviewed 26 randomly selected patients from this group and correctly identified the four patients with LMCA obstruction. There was one true and two questionable false-positive diagnoses. In a prospective study of 31 patients, two independent observers correctly identified the three patients with LMCA obstruction. There were no false negatives, and one observer had one false positive. All of the false positives were in patients with proximal left anterior descending coronary artery obstructions. Echocardiography may be a practical means of identifying patients with the LMCA obstruction.

ALTHOUGH the effect of coronary bypass surgery on the natural history of coronary artery disease is controversial, there is a consensus that surgery improves life expectancy in patients with left main coronary artery (LMCA) obstruction.1-8 This observation and the usually ominous prognosis for patients with LMCA obstruction8 have made the detection of this form of coronary artery disease extremely important. Selective coronary cineangiography provides the only reliable diagnosis of LMCA obstruction despite the efforts of many investigators using a variety of noninvasive techniques.9, 10 Thus, a practical noninvasive procedure is needed for detecting or excluding LMCA obstruction.

Since Weyman et al.7 first reported that the LMCA could be detected by two-dimensional echocardiography, there has been increasing interest in using this technique to detect LMCA obstructions.8-10 All of the studies have shown that an LMCA obstruction can be detected by two-dimensional echocardiography.7-10 However, the technical difficulty of this diagnosis renders the echocardiographic examination relatively impractical. The purpose of this study was to determine whether recent technical advances would make two-dimensional echocardiography a practical and reliable means of detecting LMCA obstructions.

Methods

All patients were examined with an Advanced Technology Laboratories 600 B two-dimensional sector scanner. The recordings were analyzed by an
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