A Reassessment of the Echocardiogram in Mitral Stenosis

By GEOFFREY D. COPE, M.B.B.S., F.R.A.C.P., JOSEPH A. KISSLO, M.D., MICHAEL L. JOHNSON, M.D., AND VICTOR S. BEHAR, M.D.

With the technical assistance of Sondra Myers, A.S.U.T.S.

SUMMARY

Echocardiographic and cardiac catheterization findings were compared in 61 patients with mitral stenosis without other significant lesions in an attempt to determine the clinical usefulness of echocardiography in the assessment of such patients. There was a poor correlation between the E-F slope on the echocardiogram and the calculated mitral valve area \( (r = 0.51) \).

A review of reported data relating the E-F slope to mitral valve area indicated that echocardiographic assessment of mitral valve area had a low sensitivity and specificity.

The amplitude of excursion of the anterior leaflet did not differ significantly in patients undergoing valvotomy and those undergoing valve replacement. The data obtained suggest that while the echocardiogram is a reliable method of diagnosing mitral stenosis, the E-F slope is an unreliable index of the severity of the lesion.

It has now become widely accepted that the echocardiogram is a useful method for evaluating the severity of mitral stenosis, the mobility and thickness of the valve leaflets and thus the suitability of the valve for replacement.\(^1\)\(^\text{a}\) However, echocardiography is still a relatively new technique, and as pointed out in a recent editorial by Joyner,\(^1\)\(^\text{b}\) the reported findings need to be critically reassessed to establish its reliability and value. We have frequently noticed discrepancies between echocardiographic and catheterization data in patients with mitral stenosis. In an attempt to define the value of echocardiography in the assessment of the severity of mitral stenosis, we have reviewed the data obtained at this hospital over the last four years in patients with this lesion who have undergone both echocardiography and cardiac catheterization.

Material and Methods

Sixty-one patients with dominant mitral stenosis are the subjects of the study. These patients had either pure mitral stenosis or mitral stenosis with only minimal \((\leq 1+)\) mitral and/or aortic regurgitation demonstrated at angiography\(^1\)\(^\text{c}\) and no other valvular lesion. The average age of the patients was 47 years (range 28 to 68 years); 13 were male and 48 female.

All patients underwent complete left and right heart catheterization including transseptal left atrial catheterization and left ventricular and aortic root cineangiography performed by standard techniques. The cardiac output was determined by the Fick principle and the mitral valve area was calculated by the formula of Gorlin and Gorlin.\(^1\)\(^\text{d}\) Mitral valve area of \(< 1.3 \text{ cm}^2\) was considered severe mitral stenosis, 1.3 to 1.8 \text{ cm}^2 moderate stenosis, and \(> 1.8 \text{ cm}^2\) mild stenosis. The cineangiograms were reviewed to determine the presence of valvular calcification.

Echocardiograms were obtained early in the series in 25 patients using a Smith-Kline Ekoline 20 ultrasonoscope and a 7.5 cm focused transducer with a frequency rate of 2.25 MHz and a repetition rate of 1000 impulses/second. The echocardiograms were photographed on Polaroid film. After mid 1972, the echocardiograms were obtained on a Unirad Series 3"C" ultrasonoscope and Tektronix graphic recorder using a similar transducer. The echocardiograms were recorded from the third, fourth, or fifth intercostal space with the patient in the supine or right shoulder forward position and the transducer was manipulated until the maximal amplitude of the anterior leaflet echoes was obtained. From mid 1972 onward, particular attention was directed to obtaining a simultaneous recording of the posterior mitral leaflet. The transducer was then rotated superiorly and medially and echoes from the aortic root and left atrium were obtained. The initial E-F slope of the anterior leaflet was determined in the standard manner\(^1\)\(^\text{e}\) and the mean of three to five readings from different cycles obtained. The amplitude of excursion of the anterior leaflet was measured as the vertical distance from the D point to the E point on the echo. Because there are frequently multiple echoes from both leaflets in systole, the D point could not always be precisely defined; in such cases this measurement could not be made. The left atrial dimension was measured from the posterior aortic wall to the posterior left atrial wall at end systole when both these points could be clearly identified.

From the Department of Medicine, Clinical Cardiology Laboratory and Cardiovascular Laboratory, Duke University Medical Center, Durham, North Carolina 27710.

Supported in part by USPHS grants HL 17679-01 and HS 01613-01. Dr. Cope is supported by an overseas fellowship from the Royal Perth Hospital, Perth, Western Australia.

Address for reprints: Joseph A. Kisslo, M.D., Duke University Medical Center, Durham, North Carolina 27710.

Received March 7, 1975; revision accepted for publication May 15, 1975.
There was a poor correlation between the E-F slope of the echocardiogram and the mitral valve area calculated by the Gorlin formula as shown in figure 1 ($r = 0.51$). The patients with the most severe stenosis (mitral valve area $\leq 1.0$ cm$^2$) had markedly decreased slopes ($< 25$ mm/sec), but patients with decreased slopes did not necessarily have severe stenosis. Of the patients with a slope between 10 and 15 mm/sec, the calculated valve areas ranged from 0.4 to 2.4 cm$^2$, and the echocardiogram was therefore of limited clinical usefulness within this range. Only with the most severe reduction of E-F slope ($< 10$ mm/sec) could severe mitral stenosis be reliably predicted. Echocardiograms from two patients with identical calculated mitral valve areas of $1.3$ cm$^2$ are shown in figure 2. It can be seen that the E-F slopes are markedly different: $4$ mm/sec in one patient and $26$ mm/sec in the other. In figure 3, echocardiograms from patients with calculated valve areas of $0.9$ cm$^2$ and $1.8$ cm$^2$ are shown. Despite the markedly different valve areas, the E-F slopes recorded in these patients are almost identical, $15$ and $16$ mm/sec, respectively.

The correlation between E-F slope and mitral valve area was not significantly improved in those patients in normal sinus rhythm compared to those in atrial fibrillation, $r = 0.57$ and 0.47, respectively.

It has been shown that severe primary pulmonary hypertension is associated with a reduced E-F slope in the absence of mitral valve disease$^{14,15}$ and it may be expected that patients with mitral stenosis with severe

The mitral valve E-F slope was significantly reduced in all patients ranging from 0 to 38 mm/sec (normal for this laboratory $> 80$ mm/sec) and in all patients in whom it was identified, the posterior mitral leaflet was seen to move in an abnormal anterior direction during diastole.

**Results**

The mitral valve E-F slope was significantly reduced in all patients ranging from 0 to 38 mm/sec (normal for this laboratory $> 80$ mm/sec) and in all patients in whom it was identified, the posterior mitral leaflet was seen to move in an abnormal anterior direction during diastole.

**Figure 1**

The relationship between E-F slope and calculated mitral valve area in 61 patients with mitral stenosis. The solid circles represent those patients with a pulmonary vascular resistance (PVR) greater than 4 units.

**Figure 2**

Echocardiograms from two patients with identical calculated mitral valve areas of $1.3$ cm$^2$. The echocardiogram on the left has a markedly reduced E-F slope ($4$ mm/sec) while that on the right has a slope of $26$ mm/sec.
reactive pulmonary hypertension would have more markedly reduced E-F slopes than patients with mitral stenosis of comparable severity without pulmonary hypertension. Fifteen patients had an increased pulmonary vascular resistance (>4 units), and all had a calculated mitral valve area of 1.4 cm² or less. As shown in figure 1, all but one had an E-F slope of 15 mm/sec or less. However, 13 patients with severe mitral stenosis without pulmonary hypertension had equally slow slopes; thus, likelihood of pulmonary hypertension cannot be predicted.

The left atrial dimension was obtained from the echocardiogram in 43 patients. The relationship between the calculated mitral valve area and this value is illustrated in figure 4. There is a wide scatter of results irrespective of the presence of sinus rhythm or atrial fibrillation.

As the catheterization and echocardiogram were not performed simultaneously, the heart rates at which the data were obtained varied. However, the mean heart rate at the time of echocardiography — 85.6 ± 24 beats/min (range 54–125) — was almost identical to the mean heart rate at the time of catheterization, 83.4 ± 27 (range 46–130). In individual patients, there was still a significant difference in heart rate on the two occasions. In order to determine whether this adversely affected the results, the correlation coefficient was determined for 20 patients in whom the heart rates were similar (within 10 beats/min) at the time of echocardiography and at catheterization. The correlation remained poor (r = 0.48) and was not significantly different from the result for the group as a whole (r = 0.51).

The patients were then subdivided into two groups, those with a reduced excursion (DE distance <20 mm) and those with a normal excursion (DE distance ≥20 mm) and the relation between E-F slope and mitral valve area compared in each group. In the group with reduced amplitude (25 patients), there was no correlation between E-F slope and valve area (r = 0.23) while in those with a normal amplitude, the correlation was better but still poor (r = 0.56).

Figure 4

The relationship between calculated mitral valve area (MVA) and the echocardiographically determined left atrial dimension in 43 patients.
In an attempt to assess the predictive value of the echocardiogram with regard to mitral valvulotomy versus mitral valve replacement, the records of 34 patients undergoing surgery were analyzed. The mean value of the amplitude of excursion for the 22 patients who underwent mitral valvulotomy was 20.0 ± 3.4 mm and for 12 patients who required mitral valve replacement, it was 16.4 ± 4.2, a difference which is not significant.

Discussion

Since the introduction of echocardiography into clinical medicine 20 years ago, its application and the popularity of the technique have considerably increased and it is now a standard part of the diagnostic evaluation of patients with valvular heart disease in most medical centers. The first cardiac abnormality to be recognized by echocardiography was the marked reduction in the diastolic E-F slope of the anterior mitral leaflet in mitral stenosis which was described by Edler in 1955.14 By the late 1960s, several large series had appeared15,16 describing the relationship of the E-F slope to the mitral valve area assessed at cardiac catheterization and surgery. From these data, it was concluded that the echocardiogram was a useful method of evaluating the severity of stenosis and the mobility of the valve. The echocardiographic diagnosis of mitral stenosis was further refined by Duchak and associates17 who described the characteristic abnormal anterior motion of the posterior mitral leaflet during diastole.

There is no doubt that the echocardiogram is a useful and qualitatively reliable method of diagnosing mitral stenosis if adequate recordings including both leaflets are obtained. This has again been confirmed in the present series in which all patients had a marked reduction in E-F slope. In all patients in whom it was adequately visualized, the posterior leaflet was found to move anteriorly during diastole. Some doubt has been cast upon the validity of this sign by the recent report of Levisman and associates,18 however, who found that the posterior leaflet moved posteriorly in 16 out of 167 patients with mitral stenosis. We have also occasionally seen patients with mitral stenosis in whom the posterior leaflet moved normally. These were patients with mild stenosis who had not undergone catheterization or who had significant associated mitral incompetence and thus were excluded from this series.

In general, there is an approximate relationship between the severity of the stenosis and reduction of the E-F slope. However, there is such a wide overlap that in an individual patient, reliable predictions of valve area based on the echocardiogram are hazardous.

The data in previously reported series do not appear to justify the conclusion of Edler4 that "the ultrasound cardiogram from the anterior mitral leaflet may be used for estimating the degree of mitral stenosis and thus deciding whether commissurotomy is indicated or not." Segal and associates3 in 1966 examined 75 patients with mitral stenosis. In their series, slopes of 10 to 30 mm/sec suggested severe stenosis; however, there was a wide overlap, particularly with higher slopes. If slopes from 25 to 45 mm/sec are considered, the valve areas in their patients ranged from approximately 0.6 to 2.5 cm² (their fig. 5). Edler4 presented data on 124 patients with mitral stenosis and compared the E-F slope to the size of the orifice estimated at operation. In patients with heavy calcification of the valve, the correlation was poor. In cases without calcification or with only slight calcification, the correlation was somewhat better. Gustafson5 presented similar data at the same time. The relationship between E-F slope and calculated mitral valve area in patients with sinus rhythm showed a correlation coefficient of 0.62, increasing to 0.67 in patients with a maximal amplitude exceeding 15 mm. The correlation between the ultrasound cardiogram and the surgically estimated valve area was described as statistically highly significant (r = 0.51). If those with an amplitude of ≤ 15 mm were excluded, the correlation coefficient was improved to 0.64. Winters and associates7 reported similar results as did Wharton and Lopez Bescos,8 who emphasized that a correlation between E-F slope and valve area could only be seen in patients with an amplitude greater than 10 mm. Winters et al.7 reported the relationship between E-F slope and amplitude of excursion. Although there was a general tendency for the slope to decrease as the amplitude decreased, there was a wide scatter. The results were not subjected to statistical analysis but the correlation was obviously not good. Mary and associates9 studied patients following mitral annuloplasty. They were unable to show a significant correlation between mitral valve orifice estimated at operation and either amplitude or diastolic E-F slope of the anterior leaflet.

Comparison of the echocardiographic and hemodynamic data in this series does not enable one to reliably predict the calculated valve area. It is possible that this may reflect inaccurate estimation of the valve area by the application of the Gorlin formula rather than the inadequacy of the echocardiogram. Previous studies, however, have shown little difference in the correlation between E-F slope and catheterization and surgical estimates of valve area. The Gorlin formula has well known potential sources of inaccuracy. Two of the most important of these have been overcome in this series by excluding

Circulation, Volume 52, October 1975
patients with significant mitral regurgitation and by directly measuring the left atrial pressure in all cases. Surgical estimates of orifice size are also subject to error from several sources. These include the fact that there is often no circulation at the time of the estimation and that surgeons attempt to quantitate the size of an irregular slit-like orifice by inserting a finger into it and thus deforming it. Despite its imperfections, the Gorlin formula remains one of the most important pieces of information on which clinical decisions are based and other preoperative methods should be judged by this criterion, particularly as an absolute figure for valve size cannot be obtained.

Patients with decreased amplitude of excursion showed no correlation between valve area and slope. These patients, as described in other series, presumably have rigid immobile valves and the size of the orifice is independent of the movement of the valve. Such patients may have pure mitral regurgitation and no detectable stenosis despite a markedly reduced E-F slope as described by Winters et al. In patients in whom adequate data were obtained, we were unable to show any significant difference in amplitude between those patients who underwent valvotomy and those who had valve replacement, although the numbers are small. Nanda et al. recently reported their experience in predicting mitral commissurotomy versus valve replacement. They estimated valve calcification by the thickness of the echoes as well as by measuring the amplitude and could correctly categorize the type of surgery in approximately two-thirds of their patients using these combined measurements.

The data from this and previous series relating the E-F slope and mitral valve area are presented in composite form in figure 5. The data from previous studies have been replotted to show the range of reported valve areas in patients with E-F slopes of <15 mm/sec, 15–25 mm/sec, 26–35 mm/sec, and >35 mm/sec. These ranges of E-F slope have been considered to represent severe, moderate and mild mitral stenosis. From these combined data, 127 out of 210 patients with severe mitral stenosis had an E-F slope of <15 mm/sec, i.e., the sensitivity was 60.5%. Of 170 patients with an E-F slope of <15 mm/sec, 127 had severe mitral stenosis, a specificity of 75%. Of 149 patients with E-F slopes of 15–25 mm/sec, 59 (39.6%) had severe, 49 (32.9%) had moderate, and 41 (27.5%) had mild mitral stenosis (fig. 6).

From these data, it would be unjustified to make

<table>
<thead>
<tr>
<th>CALCULATED MITRAL VALVE AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV Area, cm²</td>
</tr>
<tr>
<td>SEGAL (3)</td>
</tr>
<tr>
<td>WINTERS (7)</td>
</tr>
<tr>
<td>GUSTAFSON (5) Sinus Rhythm only</td>
</tr>
<tr>
<td>WHARTON (8)</td>
</tr>
<tr>
<td>PRESENT SERIES</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SURGICALLY ESTIMATED MITRAL VALVE AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV Area, cm²</td>
</tr>
<tr>
<td>EDLER (4) Light / Mod Calcium</td>
</tr>
<tr>
<td>EDLER (4) Heavy Calcium</td>
</tr>
<tr>
<td>GUSTAFSON (5)</td>
</tr>
<tr>
<td>WHARTON (8)</td>
</tr>
</tbody>
</table>

Figure 5

A summary of the data reported in the literature and in the present series comparing mitral valve area calculated by the Gorlin formula and estimated at operation with the echocardiogram E-F slope to show the distribution of mitral valve area within the E-F slope ranges of <15 mm/sec, 15–25 mm/sec, 26–35 mm/sec and >35 mm/sec. The mitral valve area is divided by the vertical dotted lines into three groups: <1.5 cm² (severe mitral stenosis), 1.5–1.8 cm² (moderately severe mitral stenosis), and >1.8 cm² (mild mitral stenosis).
important clinical decisions concerning patients with mitral stenosis on the basis of the echocardiogram.

Echocardiographers still do not agree upon the mechanism of production of the mid-diastolic closure of the mitral leaflets. One theory,\(^1\) is that following rapid early diastolic filling, the ventricular cavity distends and the papillary muscles are displaced inferiorly producing traction on the chordae, thus drawing the cusps together. At this time (mid-diastole), there is a little flow across the valve. Atrial systole forces the cusps apart as blood is propelled through them. An appropriately timed atrial systole is important in producing mitral valve closure, which occurs before ventricular systole and is probably produced by a vortex mechanism in the retrovalvular zone and a negative pressure behind the column of blood which is carried forward by its own inertia after flow across the valve has ceased.\(^2\) Similar mechanisms may account for partial closure of the mitral valve following rapid reduction of flow in mid-diastole. The movement of the mitral cusps is the result of the movement of the cusps themselves and the mitral annulus to which they are attached. Zaky et al.\(^3\) and Chakorn and colleagues\(^4\) have shown that the movement of the valve ring makes an important contribution to the descent of the anterior leaflet in diastole and that movement of the ring is influenced by the rate of ventricular filling. The E-F slope is reduced in a variety of conditions other than mitral stenosis including severe pulmonary hypertension.\(^5\) Idiopathic hypertrophic subaortic stenosis and aortic valve disease.\(^6\) This reduction has been shown to be due to diminished left ventricular diastolic compliance.\(^7\) In mitral stenosis, there is a continuous pressure gradient across the valve tending to hold the cusps apart; the cusps are thickened and rigid, fused together at their commissures and attached to thickened shortened chordae. After they have opened, the valve cusps probably move very little relative to the valve ring and the major determinant of the diastolic descent of the cusps is movement of the annulus.\(^8\) This mechanism is analogous to the motion of the cage of a mitral prosthetic valve which is a rigid structure sutured to the valve ring. The diastolic descent rate of the cage and the ball is markedly reduced compared to a normal valve in the absence of significant obstruction across the prosthesis and bears a marked similarity to the echocardiographic findings in mitral stenosis.\(^9\)

If the mechanism of production of the echocardiographic changes is as outlined above, it is not surprising that the E-F slope bears little relationship to the actual size of the orifice or the pressure gradient. It is probably determined by a combination of factors affecting mitral valve flow and the pathological changes in the valvular structures themselves.

In conclusion, the data obtained suggest that the E-F slope of the anterior mitral leaflet is in general an unreliable index of the severity of mitral stenosis. Furthermore, measurement of the amplitude of excursion of the anterior mitral leaflet alone is of little value in predicting which patients are suitable for mitral valvulotomy.

References

12. GORLIN R, GORLIN SG: Hydraulic formula for calculation of area of the stenotic mitral valve, other cardiac valves and central circulatory shunts. Am Heart J 41: 1, 1951
15. GOODMAN DJ, HARRISON DC, POPEL RL: The echocardiographic features of primary pulmonary hypertension. Am J Cardiol 33: 438, 1974
20. WINTERS WL, HOPE J, SOLOFF LA: Abnormal mitral valve motion as demonstrated by the ultrasound technique in ap-
A reassessment of the echocardiogram in mitral stenosis.
G D Cope, J A Kisslo, M L Johnson and V S Behar

Circulation. 1975;52:664-670
doi: 10.1161/01.CIR.52.4.664
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1975 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/52/4/664

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/