Measurement of Mitral Orifice Area in Patients with Mitral Valve Disease by Real-time, Two-dimensional Echocardiography

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SUMMARY
A quantitative assessment of mitral valve orifice area can be achieved in patients with pure mitral stenosis by cardiac catheterization. In the presence of mitral regurgitation, however, accurate measurement often is impossible because total diastolic flow through the mitral valve frequently is unknown. Using a recently developed real-time, two-dimensional echocardiography system, we are able to obtain cross-sectional images of the mitral valve by scanning the heart perpendicular to its long axis at the level of the tip of the mitral leaflets. Twenty consecutive patients undergoing operation for mitral valve disease were studied during the week prior to operation. In 18 of 20 (90%) the mitral orifice was imaged successfully in early diastole by two-dimensional echocardiography so that mitral valve orifice area could be measured directly in square centimeters. In 14 patients (ten with associated mitral regurgitation), mitral orifice area was measured both by echocardiography and directly at time of operation. In 12 of 14 (86%) patients, mitral orifice area by two-dimensional echocardiography was within 0.3 square centimeters of that measured at operation (correlation coefficient for all 14 patients = 0.92). We conclude that two-dimensional echocardiography is extremely useful in the evaluation of patients with mitral valve disease because it provides a noninvasive method for directly measuring the mitral valve orifice area that is accurate even in the presence of mitral regurgitation.

Additional Indexing Words:
Sector scanner
Gorlin formula
Noninvasive technique

In 1951, Gorlin and Gorlin described a method for obtaining the orifice area of narrowed valves in patients with valvular heart disease. As originally described, the pressure gradient and flow across a valve was measured at cardiac catheterization, and by the use of hydraulic formulae, an idealized orifice area was determined. The actual orifice area measured at operation or at necropsy was used to derive a constant that related the idealized orifice area to the actual orifice area. Even though this method does not measure directly the primary variable (namely, orifice size), widespread use of the formula indicates its practical utility. However, the method does have certain drawbacks; it requires cardiac catheterization and it is not applicable in the presence of mitral regurgitation when only forward cardiac output is known.

Recently, we have developed a real-time twodimensional echocardiography system that uses a mechanical sector scanner to noninvasively visualize the heart in cross-section. In the present study, we used this sector-scanning technique to cross-sectionally image the tip of the mitral valve and directly measure the mitral orifice area. Comparison with the mitral orifice area measured at operation indicates that this technique is accurate even in the presence of mitral regurgitation.

Methods
Equipment. Two-dimensional (2D) echocardiographic studies were obtained in real time using a custom-built mechanical sector scanner. This scanner consists of a standard ultrasound transducer (2.25 MHz, 1.25 cm diameter, AEROTECH transducer), an angle indicator, and a small motor. The details of this system have been described previously. The transducer directs the ultrasound signal into the chest and is angled rapidly through either a 30° or a 45° arc at a rate of 15 cycles per second. Each complete cycle results in the generation of two separate sectors (i.e., one sector is produced as the transducer moves from left to right and another as it moves from right to left). Thus, 30 separate frames (or sectors) are produced per second, each one containing 100 individual ultrasound data lines. The ultrasound signals obtained by the scanner are electronically processed by a commercial ultrasound receiver (EKOLINE 20A) and specially designed electronic circuits. The two-dimensional images are displayed on a cathode ray tube and recorded

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permanently with a closed-circuit television system. In this system, a television camera is focused on the cathode ray tube and the camera output recorded by a videotape unit. The video tapes obtained in this manner are used for subsequent analysis.

**Patient population.** The study population consisted of 20 consecutive patients undergoing operation for mitral valve disease at the National Heart and Lung Institute. Cardiac catheterization had been performed in each. Twelve were women and eight men; age ranged from 26 to 67 years. A rheumatic etiology for the mitral valve disease was presumed in all but one case. Mitral regurgitation (at least one plus on a scale of four) was documented angiographically (and confirmed at operation) in 14. Tricuspid valve disease requiring operative intervention was present in six patients and aortic valve disease requiring aortic valve replacement occurred in eight patients.

**Mitral Orifice Area Measurement**

a) **Two-Dimensional Echocardiographic Measurement.** Every patient was studied during the week prior to operation. The study was accomplished by placing the sector-scanner transducer against the patient’s chest in the third, fourth, or fifth intercostal space with the scanned sector oriented perpendicular to the left ventricular long axis; i.e., the scanned sector was oriented approximately parallel to a line connecting the left shoulder and right hip. With the scanner oriented in this manner, cross-sectional images of the heart were visualized at several levels including the base of the papillary muscles, the tip of the mitral valve, and the origin of the great arteries. Mitral orifice area was calculated by analyzing the image obtained when the scanner cross-sectioned the heart at the tip of the mitral valve leaflets. At this level, the damping and reject controls were used to clarify the orifice image. In addition, each patient’s heart was imaged parallel to the left ventricular long axis; i.e., the scanned sector was oriented approximately parallel to a line connecting the right shoulder and left hip.

Mitral orifice area was measured from a stop-frame image in early diastole (fig. 1, center panel) by tracing the orifice outline onto a piece of transparent plastic and planimetrizing the orifice area. A one square centimeter area also was traced onto transparent plastic from the centimeter calibration markers that were recorded at the end of each study. This known area was planimetered and used to convert the planimetered mitral orifice area into square centimeters. These measurements were made without knowledge of the cardiac catheterization data or the orifice area measured at operation.

b) **Operative Measurement.** Mitral orifice area was measured at operation using a custom-built sizer (fig. 2). This sizer consists of a tapered Delrin head of known dimensions mounted on a malleable silver handle. The Delrin head is 5 cm in length and is elliptical in cross-section. At the larger end, the ellipse has a major axis of 3 cm and a minor axis of 1.5 cm. The head tapers smoothly to the smaller end which has a major axis of 5 mm and a minor axis of 2.5 mm. The sizer has recessed markers that subdivide the length into 5 mm segments and allows the estimation of mitral orifice area from 3.5 cm² to 0.1 cm².

After instituting cardiopulmonary bypass but prior to valve excision, the sizer was passed by direct vision from the

![Figure 1](http://circ.ahajournals.org/)

**Figure 1**

Unretouched stop-frame images of the mitral valve orifice in early diastole obtained by a real-time two-dimensional echocardiography system (left panel and center panel). The image in the left panel is the mitral orifice of a normal subject. The image in the center panel is the mitral orifice of a patient with mitral stenosis obtained two days prior to valve replacement. In the right panel is a photograph of the intact mitral valve removed at operation from the same patient whose mitral valve orifice is shown in the center panel. One centimeter calibration marks are shown in the lower left side of each panel. Because the calibration markers are approximately the same size in each panel, the mitral orifices in the three panels can be compared directly (RV = right ventricle, S = septum, PW = posterior wall of left ventricle, AML = anterior mitral leaflet, PML = posterior mitral leaflet, PM = papillary muscle).

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left atrium into the mitral orifice. Although the sizer was firmly placed into the orifice, it was not forced; the valve was not torn and the commissures were not opened inadvertently in any patient. The recessed marker nearest the orifice was noted, the sizer removed, and the valve excised. In most cases, the valve was able to be removed intact. When this was possible, the valve again was sized. In no instances did the pre- and post-excision orifice areas differ by more than 0.3 cm².

Neither the surgeons who sized the mitral orifice at operation nor the individual analyzing the mitral orifice area by echocardiography knew of the other’s results. These data were tabulated by each separately and only at the end of the study were they compared.

Results

General Description. Satisfactory two-dimensional images of the mitral valve were obtained in 19 of 20 patients. In one patient, cardiac anatomy could not be visualized by either one- or two-dimensional echocardiography.

In 14 of 19 patients, intense reflections from some portion of the mitral valve could be seen on the two-dimensional images and suggested the presence of significant mitral valve calcification. Operative examination of the valve confirmed the presence of gross calcifications in 13 of these 14 patients. One patient not thought to have valve calcification echocardiographically was noted to have calcification at operation.

Measurement of Mitral Orifice Area. Mitral orifice area was successfully measured at operation in 16 patients. In three patients, mitral orifice area could not be measured with the sizer because a closed mitral commissurotomy was performed. In a fourth patient, technical problems at the time of operation prevented measurement.

Mitral orifice area was measured with two-dimensional echocardiography in 18 of the 19 patients with satisfactory two-dimensional images of the mitral valve. In one patient, the mitral orifice could not be visualized because of extremely intense reflections from the mitral valve. At operation, this patient was found to have both heavy calcification of the mitral valve and a small mitral orifice (0.64 cm²).

Mitral orifice area was measured successfully both at operation and by two-dimensional echocardiography in 14 patients. Significant mitral regurgitation was present in 10 of 14 (71%) patients. Figure 3 is a plot of mitral orifice area measured at operation and mitral orifice area measured echocardiographically. These data are related by the equation: Operative Mitral Orifice Area = (1.1)(2D Mitral Orifice Area) + 0.07. The correlation coefficient for these data is 0.92. In 12 of 14 (86%) patients, mitral orifice area measured echocardiographically was within 0.3 cm² of that measured at operation.

![Figure 2](image)

Photograph of the mitral valve sizer used to measure mitral orifice area at operation.

![Figure 3](image)

Plot of the mitral valve orifice area measured in 14 patients by both two-dimensional echocardiography (horizontal axis) and at operation (vertical axis). A line of identity is shown. Correlation coefficient equals 0.92.
Discussion

Although the Gorlin method has been invaluable in assessing the degree of mitral stenosis in patients with mitral valve disease, it does not directly measure mitral valve orifice area. Rather, mitral orifice area is computed by use of a hydraulic formula in which both the pressure gradient and blood flow across the mitral valve must be known. The hydraulic formula employed does not apply precisely to flow through an orifice that has depth (i.e., a funnel).\(^1\) Hence, an empirically determined constant must also be used. Moreover, the formula often is useless in estimating mitral orifice area in the presence of mitral regurgitation because total diastolic flow through the valve frequently is unknown.

Direct measurement of the mitral valve orifice area with the sector-scanning two-dimensional echocardiographic technique overcomes these difficulties. As the results of the present study demonstrate, the two-dimensional echocardiographic technique is accurate; in 12 of 14 (86\%) patients, the two-dimensional echocardiographic measurement of mitral orifice area was within 0.3 cm\(^2\) of that measured at the time of operation (and in 13 of 14 (93\%) patients was within 0.4 cm\(^2\)). Thus, the prime variable (namely, mitral valve orifice area) can be measured directly in nonoperated patients for the first time. Furthermore, the method is not influenced by the degree of mitral regurgitation, as confirmed by the close agreement between the echocardiographic and operative measurement of mitral orifice area, despite the presence of coexistent mitral regurgitation in ten of the 14 (71\%) patients. In addition, the echocardiographic technique has the obvious additional advantage over the catheterization method of being noninvasive.

The sector-scanning two-dimensional system used in the present study has several important features that may make it uniquely suited to measuring mitral valve orifice area. One feature of the system is that it allows cross-sectional images of the mitral valve to be obtained in real time. Our experience with real time imaging is that considerable improvement in image quality is obtained by minor adjustments of scanner angulation. Such image clarification is, at best, very difficult and time consuming with non-real time systems.\(^7,8\) Another important feature of the sector-scanning system is the high line density of individual stop frames. This is particularly important when attempting to image a severely stenosed mitral valve in which the orifice may be less than 2 cm in width. For example, the mitral valve orifice image of such a valve that would be obtained with the sequentially-pulsed, fixed transducer arrays\(^9,10\) would likely consist of less than six individual ultrasound data lines. In contrast, the mitral valve orifice image obtained with the sector scanner would likely be composed of 30 or more individual ultrasound data lines. Our experience with alterations in image line density has revealed that although a fivefold increase in line density does not produce a fivefold increase in resolving capability, it nevertheless does produce a clear improvement in image quality (unpublished observations). Thus, both the real-time capability and the high line density of individual stop-frame images are important features of the sector-scanning technique that make it particularly well suited to imaging the mitral orifice.

Several factors that potentially could produce an inaccurate echocardiographic assessment of mitral orifice area should be stressed. For instance, in a few

Figure 4

Diagrammatic sketch (including an unretouched stop-frame two-dimensional echocardiographic image of the mitral valve) of a cross-sectional view of the heart parallel to the long axis of the left ventricle showing the typical "bent knee" configuration of the anterior mitral leaflet in diastole that is seen in patients with mitral stenosis. If the sector scanner is placed in a high intercostal space, and oriented to cross-section the heart perpendicular to this diagram along line A-A', the scanned plane could intersect the anterior mitral leaflet near the right angle bend (arrows) and produce a false orifice. By placing the sector scanner in lower intercostal spaces, the scanned plane will not intersect the right angle bend (line B-B') and this potential error can be avoided.
patients with a very heavily calcified mitral valve, a clear mitral orifice may not be visualized. This appeared to be a major problem in one patient in the present study who had both a heavily calcified mitral valve and a small mitral orifice. In other patients, intense reflections from calcium deposits on the anterior mitral leaflet may cause the leaflet to appear thicker and thus the mitral orifice to appear smaller than its actual size. In this regard, eight of 14 patients had echocardiographically measured mitral orifice areas that were smaller than the operative measurements but in only two of 14, did the echocardiographic measurement underestimate the operative measurement by more than 0.3 cm² (and in only one of 14 did the echocardiographic measurement underestimate by more than 0.4 cm²). Thus, despite these potential problems, mitral orifice area can be measured directly and accurately by two-dimensional echocardiography in most patients.

A retrospective review of the two-dimensional images obtained from the one patient with the large discrepancy between operative and echocardiographic measurements has suggested that a problem other than heavy valve calcification also may produce inaccuracies. This potential problem is illustrated in figure 4, which is an early diastolic stop-frame image obtained with the sector scanner oriented parallel to the long axis of the left ventricle. In this image, the tips of the mitral leaflets are seen to be fused. However, that portion of anterior mitral leaflet cephalad to the fused tip is forced forward at onset of diastole by the high left atrial pressure, causing the anterior mitral leaflet to assume a “bent-knee” configuration. This configuration, characteristic of most of the patients we studied with mitral stenosis, can produce a false orifice image if the mitral valve is cross-sectioned from a high interspace. For example, if the ultrasound beam passes through the heart along line A-A’, the “bend of the knee” portion of the mitral valve could produce an image that looks deceptively like the mitral orifice. By cross-sectionally imaging the heart from the lower intercostal spaces (line B-B’) and by identifying papillary muscles before angling the scanner in a more cephalad direction to image the mitral valve orifice, this potential pitfall can be avoided.

References

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