Comparative accuracy of two-dimensional echocardiography and Doppler pressure half-time methods in assessing severity of mitral stenosis in patients with and without prior commissurotomy

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ABSTRACT This study was undertaken to compare the accuracies of the two-dimensional echocardiographic (2DE) and Doppler pressure half-time methods for the noninvasive estimation of cardiac catheterization measurements of mitral valve area in patients with pure mitral stenosis both with and without a previous commissurotomy. Data were retrospectively obtained from 74 consecutive patients who underwent cardiac catheterization within a 30 month period for evaluation of mitral stenosis, and who had two-dimensional echocardiograms performed before catheterization. Six patients (8.1%) had technically inadequate 2DE images and their data were excluded from analysis. Two of these patients had undergone commissurotomy, while the remaining four had not. Continuous-wave Doppler echocardiographic examinations were attempted in 45 patients and adequate measurements of pressure half-times were obtained in all patients studied. Mitral valve area by two-dimensional echocardiography was measured as the planimetered area along the inner border of the smallest mitral orifice visualized during short-axis scanning, while pressure half-time was calculated as the interval between the peak transmitral velocity and velocity/V2 as measured from the envelope of the Doppler spectral signal. Calculations from catheterization represented the minimal valve area at rest as derived from the Gorlin formula with the use of pressure gradients and thermodilution measurements of cardiac output. Thirty-seven of the patients had had a previous mitral commissurotomy a mean of 11.2 ± 5.4 years before, while the remaining 37 patients were previously unoperated. Mean valve area as determined at catheterization for the total group of patients ranged from 0.37 to 2.30 cm2 (mean = 1.08 ± 0.42 cm2). Linear regression analysis of data from the group of 33 previously unoperated patients revealed a good correlation between 2DE and catheterization measurements of mitral valve area (r = .83, y = 0.79x + 0.29, SEE = 0.26 cm2). Similarly, the correlation between Doppler measurements of mitral valve area were also good (r = .85, y = 0.84x + 0.17, SEE = 0.22 cm2). However, in the group of 35 patients who had undergone commissurotomy, the Doppler pressure half-time correlated much better with catheterization measurements (r = .90, y = 0.63x + 0.39, SEE = 0.14 cm2) than with 2DE estimates (r = .58, y = 0.47x + 0.61, SEE = 0.28 cm2). Reproducibility was similar for the two noninvasive methods, with a mean error of 0.14 cm2 for 2DE planimetry, and of 0.15 cm2 for Doppler pressure half-time. Thus, our data show that both 2DE and Doppler pressure half-time methods provide accurate noninvasive estimates of mitral orifice area in patients who have not undergone surgery. However, the Doppler pressure half-time is superior to two-dimensional echocardiography in estimating mitral valve area in patients who have undergone commissurotomy.

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ALTHOUGH the value of M mode echocardiography in the detection of mitral stenosis has been well established,1–3 this technique has proven to be neither sensitive nor specific in estimating actual mitral valve area.4–9 Two-dimensional echocardiography, conversely, has been shown to provide measurements of mitral valve area that correlate well with those obtained by cardiac catheterization10, 11 and direct surgical examination.12 Accordingly, echocardiography is currently the most widely used method for the noninvasive estimation of mitral orifice area. In addition, two-dimensional echocardiography has been used to plan the type of surgery to be performed in patients with mitral stenosis,13–15 and to assess the adequacy and subsequent course of surgical commissurotomy.16, 17
In 1979, Hatle et al. described an alternative noninvasive approach for estimating mitral valve area based on Doppler echocardiographic measurements of blood flow velocity across the orifice. This method employed measurement of the interval required for the Doppler-estimated transmural gradient to fall to one-half its maximal diastolic value, termed the pressure half-time. Although available data are limited, a good correlation has been found between the Doppler pressure half-time and catheterization-derived measurements of mitral valve area. However, no data currently exist comparing the Doppler pressure half-time method with two-dimensional echocardiography in the quantification of mitral stenosis, especially in patients who have undergone a previous mitral commissurotomy. Therefore, the purpose of this study was to determine the relative accuracy of these two noninvasive techniques in comparison with measurements obtained from cardiac catheterization in patients with mitral stenosis.

Methods

Patient population. The population studied consisted of 74 consecutive patients who underwent cardiac catheterization for symptomatic mitral stenosis during a 30-month period. There were 57 women and 17 men who ranged in age from 25 to 74 years (mean = 46.5). Thirty-seven of the patients had undergone a previous mitral commissurotomy, with a mean time from operation to repeat catheterization of 11.2 ± 5.4 years (range 0.2 to 25.1). Two of these patients had a closed procedure, while the remainder underwent open mitral commissurotomy. Thirty-seven additional patients had unoperated mitral stenosis at the time of study. The mean mitral valve area as obtained by catheterization for the group of 74 patients was 1.08 cm². Forty-seven of the patients were in sinus rhythm at the time of study, while 27 were in atrial fibrillation. No patient had mitral regurgitation as the predominant lesion and only six patients had 3+ mitral regurgitation during cardiac ventriculography.

Sixty-eight patients had adequate two-dimensional echocardiographic (2DE) studies, while six others were believed to be technically inadequate for determining mitral valve area and were excluded from analysis. Two of these excluded patients had a poor acoustic window, while the other four had heavily calcified and distorted mitral valves, which did not allow identification of the mitral orifice for calculation of valve areas. Of the six excluded patients, two had undergone commissurotomy, and the other four were previously unoperated. All 45 of the patients who were examined after the acquisition of Doppler instrumentation at our institution underwent a continuous-wave Doppler examination. In five of the six patients with adequate echocardiograms Doppler estimates of mitral valve area were obtained.

Two-dimensional echocardiography. All patients in the study underwent two-dimensional echocardiography, which was performed at a mean interval of 6 days before cardiac catheterization. Commercially available machines, both phased array and mechanical devices, were used to record images on videotape for subsequent playback. The smallest orifice of the mitral valve was located in the parasternal short-axis view by scanning from left atrium to left ventricle. The gain settings were then reduced until the lowest level was determined at which the entire circumference of the mitral orifice could be recorded. Multiple freeze-frame images of maximal mitral opening in early diastole were either recorded on tape or printed as hardcopy photographs for subsequent analysis. Mitral valve area in square centimeters was obtained by planimetry of the innermost border of the mitral orifice either as recorded directly on the video screen with a light-pen system or offline with a digitizing tablet (Irex Cardio-80) (figure 1). In previous work in our laboratory, no significant difference was found when these two methods were compared.

Doppler pressure half-time. Continuous-wave Doppler recordings were performed with a variety of commercially available instruments and with the use of both imaging and nonimaging transducers that operated at frequencies ranging from 2.0 to 2.5 MHz. Continuous-wave Doppler ultrasound recordings were made from the apical four-chamber view while the transducer was angled with the use of auditory and visual monitoring to locate maximal velocity across the mitral valve. No correction factor was used for the assumed intercept angle between the Doppler signal and direction of transmural blood flow. A hard-copy printout of the Doppler spectral display was obtained at paper speeds of 50 to 100 mm/sec. Subsequently, a minimum of five optimal quality beats were analyzed in patients with atrial fibrillation, while 3 beats were used in patients in sinus rhythm. Results were then averaged to produce the final results in each patient.

Figure 2 is a continuous-wave Doppler tracing obtained from a representative patient in our study. Also demonstrated is the pressure half-time method for calculating the mitral valve area. The outer border of the Doppler spectral signal represents the maximal instantaneous velocity of blood flow across the mitral valve. By calculating the time required for the maximal gradient to fall to one-half its maximal value in early diastole, the pressure half-time is obtained. This is most readily performed by dividing the maximal velocity by $\sqrt{2}$. Mitral valve area is then estimated by dividing 220 (an empirically derived constant) by the pressure half-time (in milliseconds).

Cardiac catheterization. All patients in the study underwent left and right heart catheterization for determination of mitral valve area. Mitral valve area was calculated according to the Gorlin formula with the use of mitral gradient and cardiac output. The mean mitral valve gradient was calculated by planimetry of left ventricular and pulmonary capillary wedge pressures, which were simultaneously recorded at 100 mm/sec paper speed by use of a standard fluid-filled manometer system (Statham P23). Cardiac output was determined by the thermodilution method with a Swan-Ganz pulmonary arterial catheter that was interfaced to an Edwards Cardiac Output Computer (Model 9520A). The cardiac output was determined from the mean value of three injections of iced saline. Measurements were performed in the resting basal state before contrast ventriculography or other intervention.

Data analysis. 2DE and Doppler readings were traced by two experienced echocardiographers who were unaware of cardiac catheterization data. The relationship between Doppler, 2DE, and catheterization estimates of mitral valve areas were compared by simple linear regression analysis. In a cohort of seven patients, estimates of mitral valve area by both 2DE planimetry and Doppler pressure half-time methods were performed by two separate blinded observers and compared to assess reproducibility. Differences between the observers’ measurements were expressed as a mean (cm²) for the group.

Results

Comparison of techniques. A total of 68 patients had technically adequate 2DE and cardiac catheterization
data available for analysis. 2DE valve areas obtained by planimetry ranged from 0.43 to 2.26 cm² (mean 1.16 ± 0.36). Valve area as calculated by cardiac catheterization with the use of the Gorlin equation ranged from 0.37 to 2.30 cm² (mean 1.08 ± 0.42). There was only a fair correlation by linear regression between the two methods, with a relationship of \( y = 0.62x + 0.47, r = .70, \) and an SEE = 0.26 cm².

**FIGURE 1.** Two-dimensional parasternal short-axis view of the mitral valve orifice frozen during diastole, demonstrating the echocardiographic method of mitral valve area calculation. The innermost border (dots) of the mitral orifice was planimetered with the use of a light-pen system to obtain the area (in cm²).

**FIGURE 2.** Continuous-wave Doppler spectral display of mitral diastolic flow showing the pressure half-time method for estimating mitral valve area. Point A represents the peak instantaneous velocity in early diastole. B is the point along the outer border of the spectral envelope at which the gradient has fallen to one-half its peak value. This was obtained by dividing the velocity at A by the square root of 2. C represents the pressure half-time (time in msec, from A to B) required for the pressure to fall to this value. Mitral valve area (cm²) is then obtained by dividing 220 (a constant) by the pressure half-time (C).
In 45 patients continuous-wave Doppler measurements were obtained. The Doppler estimates of mitral valve area ranged from 0.51 to 2.50 cm² (mean 1.07 ± 0.38). Linear regression analysis revealed a correlation coefficient of $r = 0.86$ and SEE = 0.20 cm².

**Reproducibility.** Seven randomly selected patients with valve areas ranging from 0.72 to 1.36 cm² by catheterization were selected from the study population to determine reproducibility of the techniques used. Mitral valve area estimates by both the Doppler pressure half-time and 2DE methods were performed by two separate blinded observers. The mean difference between observers as estimated by the Doppler method for the group of patients was 0.15 cm². Similarly, the mean difference between observers for the 2DE technique was 0.14 cm².

**Unoperated mitral stenosis (figure 3).** Within the group of 37 patients with previously unoperated mitral valves, 33 adequate echocardiograms were available. Correlation by linear regression of catheterization and echocardiographically derived valve areas was good at $r = 0.83$, SEE = 0.21 cm².

In 27 patients in the unoperated group continuous-wave Doppler estimates of mitral valve area were also obtained. The correlation was comparable to that obtained with 2DE methods at $r = 0.85$, SEE = 0.22 cm².

**Postcommissurotomy patients (figure 4).** Within the group of 37 patients who had had a previous mitral commissurotomy, 35 had adequate 2DE studies. Correlation of 2DE estimates of mitral valve area with cardiac catheterization values resulted in $r = 0.58$, SEE = 0.28 cm². Thus, mitral valve orifice measurements...

**FIGURE 3.** Linear regression analysis of data from 37 patients with unoperated mitral stenosis, showing the relationship between 2DE (top) and Doppler (bottom) estimates of mitral valve area as compared with results of catheterization. The correlation coefficients were comparable ($r = .83$ and .85) and were not statistically different for the two methods in this group of patients.

**FIGURE 4.** Linear regression analysis comparing 2DE (top) and Doppler pressure half-time (bottom) methods of estimating mitral valve area vs results of cardiac catheterization in 37 patients with a previous commissurotomy. The Doppler method ($r = .90$, SEE = .14) was more accurate than 2DE planimetry ($r = .58$, SEE = .28) in this group of patients ($p < .05$).
are less accurate (p < .05) in postcommissurotomy patients than in those who have not had this procedure.

Eighteen patients who had undergone commissurotomy were examined by continuous-wave Doppler echocardiography. Correlation of the Doppler-estimated mitral area with cardiac catheterization values in these patients was excellent at \( r = .90 \), SEE = 0.14 cm\(^2\).

Results in patients examined by both techniques. We further studied the relationship of 2DE and Doppler estimates of mitral valve area by comparing these values of catheterization data in the subgroup of 45 patients in whom both procedures were performed. The relative accuracies of these techniques did not change significantly in this cohort. Thus, in the 18 postcommis- surotomy patients, correlation between catheterization and 2DE estimates of mitral valve area was \( r = .78 \), SEE = 0.26 cm\(^2\); while the correlations with catheterization data for the 27 unoperated patients who underwent both 2DE and Doppler examinations were \( r = .86 \), SEE = 0.22 and \( r = .85 \), SEE = 0.23, respectively.

Discussion

In patients with mitral stenosis, the symptoms of dyspnea and fatigue are often difficult to quantify and do not always reflect genuine reductions in mitral orifice area.\(^{22}\) Therefore, the ability to accurately assess valve area by noninvasive techniques is of great importance to the management of patients with mitral stenosis. Previous studies have demonstrated that two-dimensional echocardiography provides a reliable method by which to quantitate mitral orifice size.\(^{10-12}\) The results of this study demonstrate that Doppler recordings provide an alternate modality for the assessment of mitral valve area that are (1) available in some patients in whom technically adequate two-dimensional echocardiograms cannot be obtained, (2) comparable in accuracy to two-dimensional echo-grams in patients with unoperated mitral stenosis, and (3) yield measurements of mitral valve area that are superior in accuracy to those of two-dimensional echocardiography in postcommissurotomy patients.

The central role of two-dimensional echocardiography in the diagnosis, management, and follow-up of patients with mitral stenosis is now well established. Echocardiography allows for a direct and noninvasive measurement of true anatomic orifice. Previous studies comparing measurements by two-dimensional echocardiography with those by the Gorlin equation with values derived from cardiac catheterization have reported correlation coefficients of \( r = .83 \) to \( r = .95.\)\(^{10-12, 14, 23}\) These studies excluded 15% to 28% of patients on the basis of technically inadequate two-dimensional studies, and included a wide range of stenoses, with valve areas of up to 4.4 cm\(^2\). We attempted to include data from all patients; therefore, we excluded only 8.1% of the patients in whom echocardiography was attempted. In addition, 90% of our patients had mitral valve area measurements by the Gorlin formula of 1.6 cm\(^2\) or less, and only one had a mitral valve area of greater than 2 cm\(^2\). Accordingly, the correlation coefficient (\( r = .83 \)) between the estimates obtained by the 2DE method and those obtained with the Gorlin formula in unoperated patients with mitral stenosis in this study compares favorably with that reported in the literature.

Despite the good results that have been previously obtained, many significant pitfalls exist in the application of two-dimensional echocardiography to the quantitation of mitral valve area. The primary limitation of two-dimensional echocardiography in the measurement of the mitral orifice is the adequacy, or lack thereof, of image quality. Thus, a small or absent thoracic window or the presence of impediments to ultrasound transmission may preclude the ability to achieve adequate visualization of the mitral valve orifice. The presence of fibrosis, calcification, and commissural fusion along with chordal and papillary muscle involvement may cause severe distortion of the mitral leaflets (figure 5). The doming of the mitral leaflets typically result in the configuration of a curtain between left atrium and left ventricle during diastole. The mitral orifice is therefore presented as a target of limited size with the smallest diameter being localized to only a small area in the parasternal short-axis view. Henry et al.\(^{12}\) have pointed out the possibility of creating a "false orifice" if careful attention is not paid to the transducer angulation with respect to the doming anterior mitral leaflet. Several authors have also noted that 2DE scanning with high-gain settings may result in underestimation of the true orifice area due to the "blooming" effect from the thickened leaflets.\(^{10-13}\) Conversely, Martin et al.\(^{23}\) have pointed out that low-gain settings may lead to image dropout and result in falsely large estimates of orifice size.\(^{23}\) Therefore, although two-dimensional echocardiography has been shown to yield reliable data concerning the severity of mitral stenosis, it is technically demanding, requires experience and expertise, and may not be feasible in some patients.

The Doppler pressure half-time method used in this study is derived from a technique first used by Libanoff and Rodbard\(^{24}\) to calculate mitral valve area from
cardiac catheterization data. Both the pressure half-time and the Gorlin equations are based on Torricelli's law governing steady flow through an orifice.

\[ \Delta P = \frac{1}{2} E V_{max}^2 \]

where \( \Delta P \) = pressure gradient; \( E \) = mass density of fluid; and \( V_{max} \) = maximum fluid velocity.\textsuperscript{25} The method proposed by Libanoff and Rodbard involved calculation of the time required for the diastolic pressure gradient between left atrium and left ventricle to fall to one-half its maximal value. This approach has the advantage over the Gorlin equation of being relatively independent of heart rate and cardiac output. Theoretically, the Doppler estimate obtained by a similar technique should be more analogous to catheter-derived measurements than those obtained by two-dimensional echocardiography, since the pressure half-time and catheterization measurements both use physiologic parameters of flow through a restricted orifice, while two-dimensional echocardiography provides an anatomic estimate of orifice size at a single point during diastole. A potential advantage of the Doppler pressure half-time technique over two-dimensional echocardiography is apparent in patients with atrial fibrillation. Maximal early diastolic opening may be difficult to discern by two-dimensional echocardiography in patients who have very irregular rhythms,\textsuperscript{23} while Doppler spectral signals show minimal variation in the rate of decline from peak velocity, despite irregular rhythms.\textsuperscript{18}

The Doppler pressure half-time measurement is not without its clinical limitations. The constant of 220 used to calculate mitral valve area has been derived empirically in a group of patients with mitral stenosis, and may not be directly applicable to individual subjects. In addition, accurate measurement of the pressure half-time is dependent on a clear definition of the envelope of a continuous-wave Doppler signal. Lack of a well-defined continuous edge of the Doppler signal can lead to errors in the derivation of measurements of mitral orifice size. Nevertheless, Hatle et al.\textsuperscript{18} have shown that application of the pressure half-time method to the Doppler velocity signal can yield accurate noninvasive estimates of mitral orifice area in patients with mitral stenosis.

The results of this study indicate that Doppler and 2DE measurements of mitral valve area correlate equally well with values obtained from cardiac cath-
eterization in patients with unoperated mitral stenosis. Thus, correlation coefficients for results with the Gorlin formula vs those with the two echocardiographic techniques were $r = .85$ and $.83$ for Doppler and two-dimensional echocardiography, respectively. In addition, the Doppler examination produced acceptable velocity signals in all patients studied, whereas four of the patients in this group had technically inadequate echocardiogram that precluded quantitation.

Previous studies have examined the ability of two-dimensional echocardiography to measure mitral valve area in postcommissurotomy patients only in the early postoperative period. This work has indicated that two-dimensional echocardiography compared favorably with cardiac catheterization in quantitating mitral orifice size in the period shortly after surgery. However, the process of severe calcification and fibrosis has been shown to continue to occur and to distort valve architecture in nearly 40% of patients for another 10 to 15 years. This investigation presents the first systematic evaluation of the ability of two-dimensional echocardiography to assess mitral valve area in the late postoperative period after commissurotomy. In our study we were able to assess the valve area by two-dimensional echocardiography in 35 of 37 patients who had been followed for a mean interval of 11.2 years before they required repeat catheterization for recurrent symptoms. We observed that the estimation of mitral valve area by planimetry of two-dimensional echocardiograms is more difficult in such patients due to extensive distortion and thickening of the leaflets. Thus, a two-dimensional echocardiogram does not appear to be as accurate in the estimation of the mitral valve area after commissurotomy as it is in unoperated patients.

In comparison to two-dimensional echocardiography, Doppler techniques proved to be substantially more accurate in estimating mitral valve area in postcommissurotomy patients. Thus, the correlation coefficient for the Doppler method ($r = .90$) was superior to that for two-dimensional echocardiography ($r = .58$). In addition, Doppler data could be obtained in five patients in whom two-dimensional echocardiograms were technically inadequate. Based on these observations, Doppler echocardiography would seem to be the noninvasive modality of choice for the assessment of mitral valve area in patients with mitral stenosis who have previously undergone commissurotomy.

**Limitations of the study.** Thermodilution measurements of cardiac output are known to have potential inaccuracies in patients with regurgitant lesions since only forward flow and output is evaluated. Therefore, thermodilution can lead to an underestimation of orifice size, and is most useful in providing an estimate of the minimal valve area. The group of 74 patients in this study were selected for the presence of relatively pure mitral stenosis, and only a few patients had significant mitral regurgitation demonstrated by ventriculography. Both 2DE and Doppler pressure half-time methods resulted in a slight overestimation of valve areas determined at catheterization by the thermodilution technique (illustrated by a positive y intercept in figures 3 and 4). This discrepancy may be due to the presence of mitral regurgitation in some patients in this study. In this regard, it is noteworthy that the Doppler pressure half-time is not flow dependent, and therefore may be more accurate in determining a “true” mitral valve area as measured by angiographic methods in patients with combined mitral stenosis and regurgitation.

The criteria for entry into this study were the presence of adequate catheterization pressure and flow data for the calculation of valve areas and a two-dimensional echocardiogram recorded between 1982 and 1985. However, only 45 of these patients had a Doppler examination, since the technique was not being used routinely in our laboratory in 1982. If only data from the 45 patients in whom catheterization, echocardiography, and Doppler studies were all performed are analyzed, the relative accuracies of these tests do not change significantly. Thus, for the 27 patients with unoperated mitral stenosis, the comparisons of catheterization data with those obtained by Doppler and two-dimensional echocardiography yielded a correlation coefficient of $r = .86$ and an SEE of 0.22. In the 18 postcommissurotomy patients, the correlation between 2DE and catheterization-derived mitral valve area was $r = .78$, SEE = 0.26 cm²; while for the same group comparison of catheterization results with those obtained by the Doppler method resulted in $r = .90$, SEE = 0.14 cm². The inclusion of patients for whom only two-dimensional echocardiograms were available enabled us to analyze our results in a larger number of patients with varying severities of valvular obstruction.

On the basis of the foregoing experience, 2DE imaging and Doppler velocity recordings have assumed a complementary role in the assessment of the patient with mitral stenosis in our laboratory. Two-dimensional echocardiography provides information regarding valvular anatomy, and thus is of potential use in evaluating the feasibility of commissurotomy in the preoperative period. Doppler pressure half-time provides data regarding the physiologic or functional valve area.
the patient with unoperated mitral stenosis, both 2DE images and Doppler pressure half-time methods provide accurate noninvasive estimates of mitral orifice size. In the postcommissurotomy patient, the addition of Doppler estimates of mitral valve area significantly enhances the accuracy of noninvasive assessment of obstruction. Together, the two ultrasound techniques can be used to confirm each other, and substantially increase the certainty with which the noninvasive valve area can be viewed.

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References
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