JACC Vol. 28, No. 5
November 1, 1996:1190–7

Measurement of Mitral Valve Area in Mitral Stenosis: Four Echocardiographic Methods Compared With Direct Measurement of Anatomic Orifices

FRANCESCO FALETRA, MD, ANTONIO PEZZANO, JR., MD, ROSSANA FUSCO, MD, ANTONIO MANTERO, MD, ROBERTO CORNO, MD, WILMA CRIVELLARO, MD,* FRANCESCA DE CHIARA, MD, ETTORE VITALI, MD, VELIANO GORDINI, MD, PAOLA MAGNANI, MD, ANTONIO PEZZANO, SR., MD

Milan, Italy

Objectives. **This study sought to compare the mitral valve areas of patients with rheumatic mitral valve stenoses as determined by means of four echocardiographic and Doppler methods with those obtained by direct anatomic measurements.**

Background. **There has been no systemic comparison between Doppler-determined valve areas and the true anatomic orifice in a single cohort.**

Methods. **In 30 patients with mitral stenosis, the mitral valve areas determined by two-dimensional echocardiographic planimetry, pressure half-time, flow convergence region and flow area were compared with the values directly measured on the corresponding excised specimen by means of a custom-built sizer.**

Results. **The correlation coefficient was $r = 0.95$ (SE 0.06, $p < 0.0001$) for two-dimensional planimetry; $r = 0.80$ (SE 0.09, $p < 0.0001$) for pressure half-time; $r = 0.87$ (SE 0.09, $p < 0.0001$) for flow convergence region; and $r = 0.54$ (SD 0.1, $p < 0.002$) for flow area. Two-dimensional echocardiographic planimetry, pressure half-time, flow convergence region and flow area overestimated the actual anatomic orifice by >0.3 cm^2 in 2, 1, 6 and 0 patients, respectively, and underestimated it by >0.3 cm^2 in 0, 4, 1 and 8 patients, respectively.**

Conclusions. **Mitral valve areas determined by two-dimensional planimetry, pressure half-time and proximal flow convergence region reliably correlated with size of the anatomic orifice. The flow area method provided a less reliable correlation.**

(J Am Coll Cardiol 1996;28:1190–7)

Two-dimensional planimetry and the mitral pressure half-time derived from Doppler data are currently the most widely used techniques for estimating mitral valve area in patients with mitral stenosis (1–6). Two other methods, both based on color Doppler flow imaging, have recently been described: the proximal isovelocity surface area (PISA) (7) and the flow area method (8). The first uses the flow convergence region proximal to the valve to derive the instantaneous flow rate and therefore calculate the mitral valve area by means of the continuity equation: the second is based on the assumption that the width of the color jet passing through a stenotic orifice is an indirect indicator of orifice size and that accurate measurement of the jet diameters should provide a quantitative assessment of the severity of mitral stenosis.

With few exceptions (1), the accuracy of these various methods (2–10) has been validated by comparison with valve area values calculated by means of the Gorlin formula (11,12) during cardiac catheterization. This formula uses hydrodynamic principles that are primarily related to the area occupied by flow (i.e., effective area), which is somewhat smaller than the anatomic area of the orifice because of the tendency of a fluid to stream centrally (13). On the basis of the differences observed in 11 patients in whom the mitral valve area was verified by means of digital palpation during operation or in necroptic specimens, Cohen and Gorlin (12) introduced a coefficient of contraction (ratio of effective vs. anatomic area) of 0.85, which was thought to provide a measure closer to the anatomic area of the valve. However, various reports (14,15) have emphasized that the ratio between the effective and anatomic area cannot be considered constant and that the area calculated using the Gorlin formula may vary quite considerably from the size of anatomic orifice, depending on flow and pressure conditions; moreover this formula only provides an indirect measurement of valve area. Thus, the correlations between the valve areas measured by these various noninvasive echocardiographic and Doppler methods and the true anatomic area of the orifice have not yet been fully investigated.

The present study was therefore designed to compare the valve areas determined by means of two-dimensional echocardiographic planimetry, and the pressure half-time, PISA and

From the Central Cardiology Service and Cardiac Surgery Division, "A. De Gasperis" Cardiology Department, Niguarda Hospital and *Consiglio Nazionale delle Richerche Institute of Clinical Physiology (Section of Milan), Milan, Italy.

Manuscript received January 31, 1996; revised manuscript received June 12, 1996, accepted June 26, 1996.

Address for correspondence: Dr. Francesco Faletra, Via G. Taccioli 20, 20161 Milan, Italy.

0735-1097/96/$15.00
PII S0735-1097(96)00326-9

flow area methods with the direct anatomic measurement of corresponding valve specimen.

Methods

Patients. During an 18-month period, all patients with a diagnosis of mitral stenosis scheduled for mitral valve replacement at the De Gasperis Cardiac Surgery Division, Milan, underwent two-dimensional, Doppler and color Doppler study 2 to 7 days before operation. Patients with an associated aortic insufficiency ≥2+ (measured by color Doppler on a scale of 0+ to 4+), severe left ventricular dysfunction or left ventricular hypertrophy were excluded from the study. Of the 38 patients initially enrolled, 4 were subsequently excluded from the final data analysis because of inadequate two-dimensional (n = 3) or color Doppler imaging (n = 1) and a further 4 patients because the valve was not removed en bloc (n = 1) or because an extensively distorted valve orifice prevented any accurate measurement (n = 3). The final group therefore included 30 patients (25 women, 5 men; mean age [±SD] 56 ± 8.9 years, range 29 to 73).

Echocardiographic examination. All examinations were performed using a commercially available wide-angle phased array imaging system (Acuson 128 XP 10 C) equipped with a 3.5-MHz transducer. The echocardiographic, Doppler and color Doppler studies were performed using the same transducer.

Two-dimensional planimetry. The mitral valve orifice was visualized in the standard parasternal short-axis view, with the scan plane positioned in such that it was parallel to and passed directly through the valve orifice (2,3) (Fig. 1A). The smallest anatomic valve orifice was imaged either by slightly sweeping in a caudally cephalad direction or by appropriately angling the scan plane. The maximal diastolic leaflet distension in each patient was chosen by selecting single frames of the images stored in the cine-loop memory; the settings were optimized to image a virtually complete mitral valve orifice without the overlap of "fluffy" signals. In the presence of extensive calcifications, gain was appropriately adjusted downward until the inner orifice borders were optimally visualized without any signal dropout at their margins. The inner edges of the mitral leaflets were then directly planimetered from the video screen using the machine's built-in software package. Five consecutive orifice areas were averaged, and the mean results were calculated for each patient.

Pressure half-time method. A continuous wave Doppler tracing of transmitral flow was recorded under color Doppler guidance in the apical four-chamber view and stored in the cine-loop memory. Pressure half-time was measured, and valve areas were directly calculated using the machine's built-in software package (Fig. 1B). Only the beats with diastolic filling period >300 ms were analyzed because the pressure half-time could not be reliably measured with shorter beats. To avoid artifactual distortion in the shape of the curve, the intercept angle between the mitral jet and ultrasound beam was kept constant throughout diastole. Five consecutive orifice areas were averaged, and the mean results were calculated for each patient.

PISA method. The flow convergence region proximal to the stenotic mitral orifice during diastole was imaged in the apical four-chamber view (Fig. 1C). Color gain was standardized by starting at maximal gain and then adjusting downward until background noise had just disappeared. An aliasing velocity of 24 cm/s was used by adjusting the zero baseline shift. The maximal extension of the flow convergence region in a cardiac cycle was selected using the cine-loop function. The shape of the isovelocity surface was assumed to be a hemisphere, and the distance from the first red–blue aliasing to the edge of the leaflets on the left atrial side was then measured (R). The funnel angle ϕ formed by the mitral leaflets and containing the flow convergence region was measured in the same frame using an off-line system. The maximal mitral flow rate Q was calculated as the product of $2\Pi R^2) \times (Av) \times (\phi/180)$, where Av is the aliasing velocity (cm/s), and $\phi/180$ is the factor that accounts for the inflow angle ϕ (7). The mitral valve area was then calculated according to the continuity equation A = Q/V, where V (cm/s) is the peak transmitral velocity in diastole recorded by continuous wave Doppler. The radius, angle and peak velocity were measured and averaged for 5 consecutive beats for each patient.

Flow area method. Color gain was standardized by starting at maximal gain and then adjusting downward until background noise had just disappeared. An aliasing velocity of 54 to 70 cm/s was used. Given that excessive gain on the anatomic image might obscure flow on the color flow displays, two-dimensional gain was also adjusted slightly downward (8); the narrowest sector angle capable of displaying a flow jet at the orifice was then used for each patient. The width of the central laminar core of the jet measured at the mitral valve orifice in the apical long-axis and the 90° perpendicular scan plane were considered respectively the minor (a) and major (b) diameter of the ellipse forming the valve orifice (Fig. 1, D and D′). Five consecutive minor and major diameters were averaged, and the mean results were calculated for each patient. The valve area was then calculated by applying the equation for the area of an ellipse: $(\pi/4) \times (a \times b)$.

Specimen measurement. The sizer used in the present study was built according to Henry's indications (1). It was 5 cm long and elliptical in cross section; at the larger end, the ellipse had a major axis of 3 cm and a minor axis of 1.5 cm. The head tapered smoothly to the smaller end, which had a major axis of 5 mm and a minor axis of 2.5 mm. The sizer had recessed markers tht subdivided the length into 5-mm segments and allowed mitral orifice areas of 3.5 to 0.1 cm^2 to be estimated (Fig. 2A). The mitral valves were removed en bloc from all 30 patients, and to avoid the effects of valve shrinkage, the measurements were made immediately after removal. The sizer was placed firmly in the orifice but was never forced; the valve was not torn nor were any commissures inadvertently opened in any patient. The recessed marker nearest the commissural edges of the orifice was noted (Fig. 2, B and C). When the edges of the orifice were between two markers, the

JACC Vol. 28, No. 5
November 1, 1996:1190–7

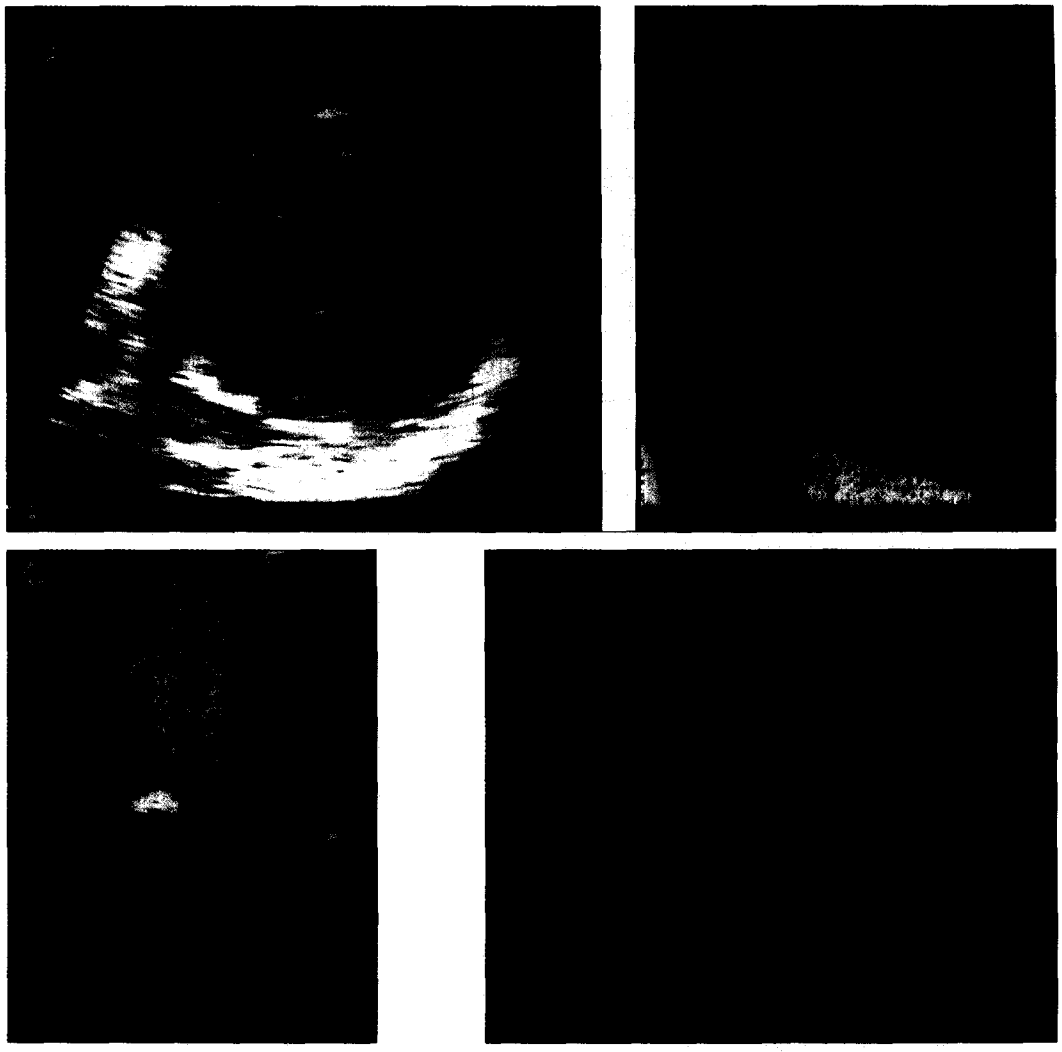


Figure 1. Composite figure showing representative examples of the four methods used. **A,** *Two-dimensional planimetry.* The mitral valve orifice is visualized in the standard parasternal short-axis view. The inner edges of the mitral leaflets are directly planimetered (**dotted area**) from the video screen using the machine's built-in software package. **B,** *Pressure half-time method.* A continuous wave Doppler tracing of transmitral flow was recorded under color Doppler guidance in the apical four-chamber view and stored in the cine-loop memory. Pressure half-time was measured, and valve areas were directly calculated using the machine's built-in software package. **C,** *Flow convergence region method.* **Arrows** indicate the first red (yellow)–blue aliasing, where r is the distance from the first red–blue aliasing to the edge of the leaflets on the left atrial side. **White lines** delimit the angle ϕ formed by the mitral leaflets. The maximal mitral flow rate Q is calculated as the product of $(2\Pi R^2) \times (Av) \times (\phi/180)$, where Av is the aliasing velocity (cm/s), and $\phi/180$ is the factor that accounts for the inflow angle ϕ (7). The mitral valve area is then calculated according to the continuity equation A = Q/V, where V (cm/s) is the peak transmitral velocity in diastole recorded by continuous wave Doppler. **D and D',** *Flow area method.* **Arrows** indicate the edges of the central laminar core of the jet, which is measured at the mitral valve orifice in the apical long-axis (**D**) and 90° perpendicular scan plane (**D'**). The valve area is then calculated by applying the equation for the area of an ellipse: $(\pi/4) \times (a \times b)$. LV = left ventricle; RV = right ventricle.

intermediate value was taken. The data were tabulated separately by one of the the authors (A.P.,Jr.), who had no knowledge of the two-dimensional, Doppler and color Doppler results, and were compared with the echocardiographic results only at the end of the study.

Reproducibility of measurements. The valve area measurements based on the four methods were repeated in a subgroup of 10 randomly selected patients by a second observer (R.F.) who had no knowledge of the results from the first set of measurements. The mean value ± SD of the differences between observations was 0.04 ± 0.08 cm^2 for the mitral valve area determined by two-dimensional planimetry, 0.04 ± 0.09 for those determined by the Doppler pressure half-time method, 0.05 ± 0.08 cm^2 for those determined by the flow convergence region method and 0.04 ± 0.12 for those determined by the flow area method.

Statistical analysis. Results are expressed as mean value ± SD. Simple linear regression analysis was used to compare the two-dimensional planimetry, Doppler pressure half-time, flow convergence region and flow area methods with the actual orifice of the valve specimen and SE depicted. A p value <0.05 was

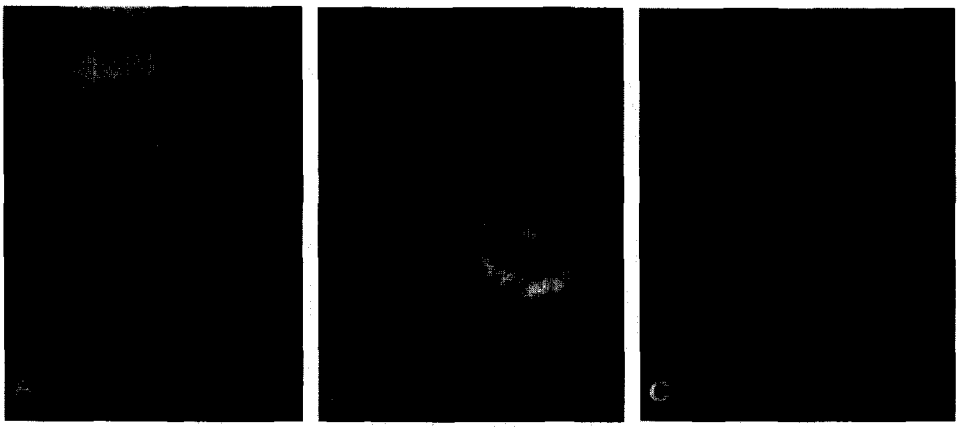


Figure 2. A, The custom-built sizer and a valve specimen. **B,** The sizer completely fits the valve orifice. **C,** The valve orifice is measured by reading the recessed marker nearest the commissural edges of the specimen.

considered statistically significant. Because variations in the estimate of the valve area >0.3 cm^2 may affect decisions concerning patient management, any divergence from the anatomic reference >0.3 cm^2 was considered the cutoff limit for assessing the accuracy of the method tested.

Results

Twelve patients were in sinus rhythm, and 18 had atrial fibrillation. Nine patients had pure mitral stenosis; 10 had associated mitral insufficiency ≤2+; 1 had associated mitral insufficiency ≥2+; and 19 had associated aortic insufficiency ≤2+.

The mitral valve areas measured in each patient using the four methods as well as the direct measurements of the valve specimens are shown in Table 1. Calcifications of the mitral leaflets mainly involving the commissures were found in 16 patients.

The orifice area of the valve specimens measured by the custom-built sizer ranged from 1.4 to 2 cm^2 (mean 1.2 cm^2).

Two-dimensional planimetry. The mean value of the valve area was 1.2 ± 0.4 cm^2 (range 0.7 to 1.97). There was excellent correlation (r = 0.95, SE 0.06, p < 0.0001) between the two-dimensional planimetry and anatomic areas. In two patients the planimetric area overestimated but in no patients underestimated, the anatomic orifice size by >0.3 cm^2 (Fig. 3).

Pressure half-time method. The mean value of the valve area was 1.1 ± 0.3 cm^2 (range 0.7 to 1.8). There was good correlation (r = 0.80, SE 0.09, p < 0.0001) between the valve areas determined by the pressure half-time method and those revealed by direct anatomic measurement. In one patient the method overestimated and in four patients underestimated the anatomic orifice size by >0.3 cm^2 (Fig. 4).

PISA method. The mean value of the valve area was 1.3 ± 0.4 cm^2 (range 0.6 to 2.1). There was good correlation (r = 0.87, SE 0.09, p < 0.0001) between the valve areas determined by the PISA method and those revealed by direct anatomic measurement. In six patients the method overestimated and in one patient underestimated the anatomic orifice size by >0.3 cm^2 (Fig. 5).

Flow area method. The mean value of the valve area was 0.9 ± 0.3 cm^2 (range 0.4 to 1.6). The correlation between the valve areas determined by the flow area method and those revealed by direct anatomic measurement was less reliable (r = 0.54, SE 0.1, p < 0.002). The method did not overestimate

Table 1. Clinical and Echocardiographic Evaluation in 30 Study Patients

Pt No.	Age (yr)/ Gender	2D Planimetry (cm^2)	PHT (cm^2)	FCR (cm^2)	Flow Area (cm^2)	AVA (cm^2)
1	60/M	1.7	1.2	1.6	0.8	1.7
2*	62/F	1.1	0.9	1.9	0.9	0.9
3*	52/F	2.0	1.8	2.0	0.8	2.0
4*	63/F	1.5	1.6	1.5	1.2	1.6
5	63/F	1.6	1.5	1.6	0.9	1.6
6*	58/M	1.0	1.0	0.8	0.8	1.0
7	63/F	0.7	0.7	0.8	0.7	0.8
8*	61/F	1.7	1.4	1.9	0.7	1.6
9	56/F	1.1	0.9	1.1	1.2	1.2
10†	29/F	1.1	0.7	0.8	0.7	0.7
11	50/F	1.4	1.0	1.4	1.1	1.2
12*	55/F	1.5	1.1	1.4	1.0	1.4
13	73/M	1.4	1.4	1.3	1.4	1.4
14*	51/F	1.1	0.9	1.2	0.9	1.2
15	71/F	0.7	0.8	1.2	0.4	0.6
16	48/F	1.4	1.0	1.3	1.2	1.0
17*	53/F	1.8	1.8	2.1	1.6	1.8
18*	57/F	0.8	0.8	0.9	0.6	0.8
19	52/F	1.8	0.9	1.7	1.2	1.8
20	66/F	1.9	1.5	1.6	1.0	2.0
21	42/F	0.9	1.3	1.0	0.9	0.9
22	51/F	1.1	1.0	0.9	0.9	1.0
23	70/F	0.8	0.8	0.6	0.8	0.8
24	56/F	1.1	1.1	1.1	1.0	1.0
25*	56/F	1.5	1.1	1.5	1.3	1.5
26	45/F	0.9	0.9	1.2	0.8	0.9
27	56/F	0.8	0.7	1.9	0.7	0.9
28	58/M	0.9	0.9	1.3	0.9	0.9
29	51/M	0.9	0.8	0.9	0.7	0.9
30	60/F	1.1	0.9	1.2	1.0	1.1
Mean ± SD	56 ± 9	1.2 ± 0.4	1.1 ± 0.3	1.3 ± 0.4	0.9 ± 0.3	1.2 ± 0.4
Range	29–73	0.7–2	0.7–1.8	0.6–2.1	0.4–1.6	0.6–2

*Trivial to mild mitral insufficiency. †Moderate to severe mitral insufficiency. AVA = anatomic mitral valve area measured in valve specimen; F = female; FCR = flow convergence region; M = male; PHT = pressure half-time; Pt = patient; 2D = two dimensional.

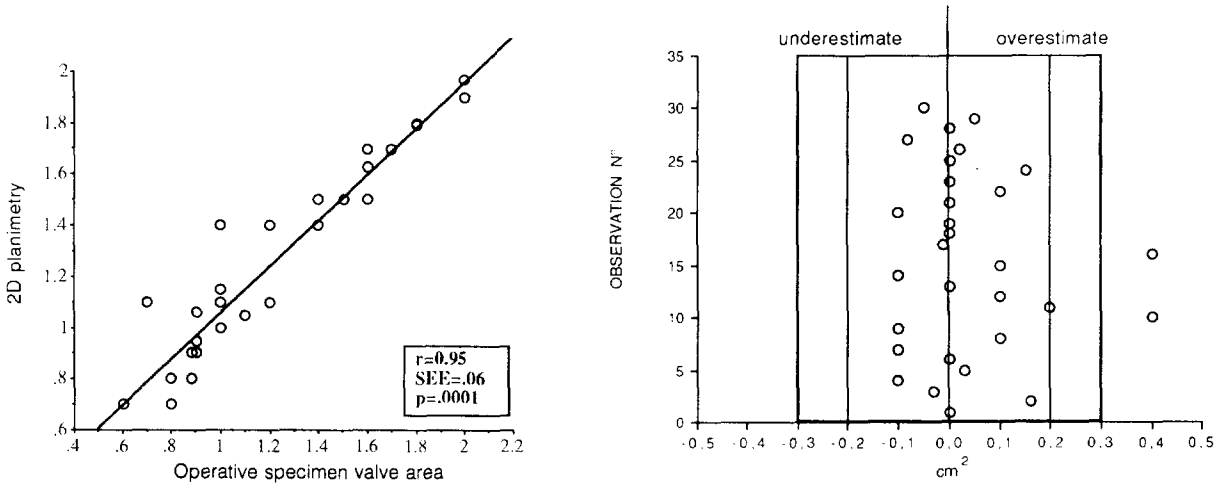


Figure 3. Left, Comparison between mitral valve areas measured by two-dimensional (2D) planimetry and those measured in the corresponding valve specimen. **Right,** Differences between values of mitral valve areas measured by two-dimensional echocardiography versus specimen valve areas. All but three of the discrepancies are within the range of 0.2 cm^2.

the anatomic area in any patient, but it did underestimate the orifice size by >0.3 cm^2 in eight patients (Fig. 6).

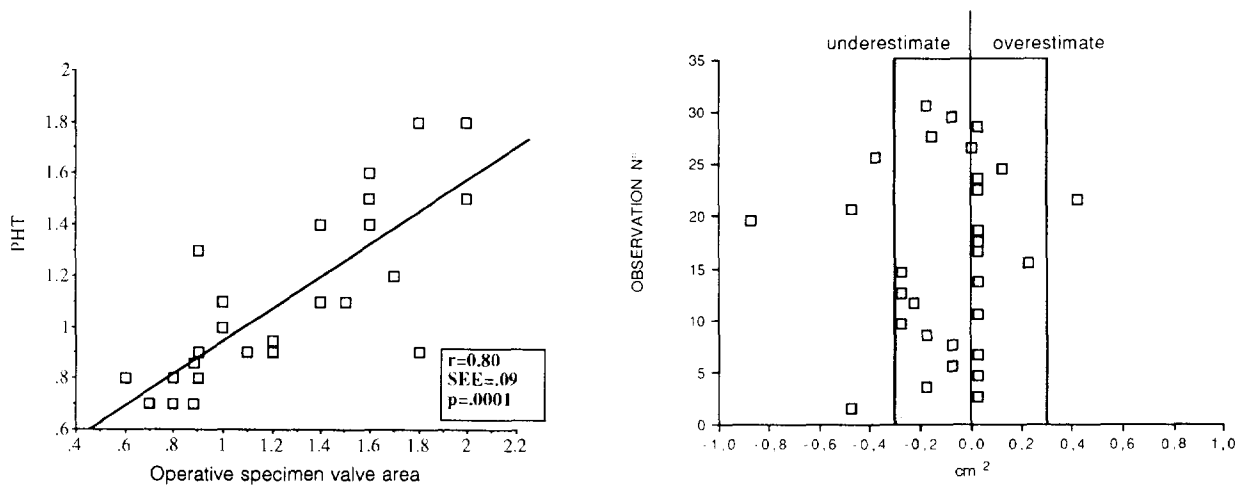
Patients with associated mitral regurgitation. Eleven patients with an associated mitral insufficiency (trivial to mild in 10, moderate to severe in 1) were separately analyzed. For each of the four methods, the mean deviation from the anatomic value was no different from that observed in patients with mitral stenosis only (Table 2).

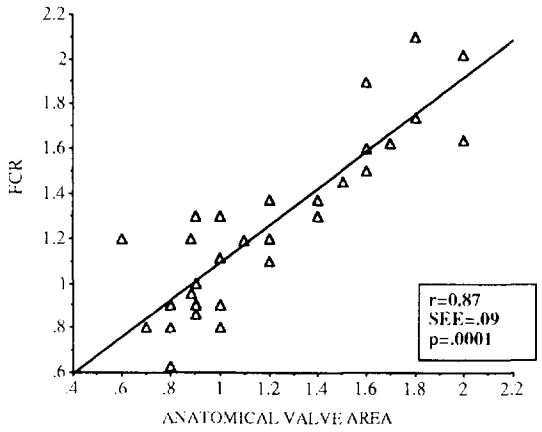
Figure 4. Left, Comparison between mitral valve area measured by pressure half-time (PHT) and those measured in the corresponding valve specimen. **Right,** Differences between values of mitral valve areas measured by pressure half-time versus specimen valve areas. In four patients the difference is >0.3 cm^2 (toward underestimation).

Discussion

The primary goal of all noninvasive methods used for measuring mitral valve areas should be to provide an estimate of valve area that is as close as possible to actual anatomic values. To our knowledge, this is the first study to systematically compare mitral valve areas measured by means of two-dimensional planimetry, pressure half-time, PISA and flow area methods with direct anatomic measurement of the corresponding orifices in a single patient cohort.

Two-dimensional planimetry and anatomic orifice. As expected, two-dimensional planimetry showed excellent correlation with anatomic orifice size: In all but two patients (93%), it was within 0.3 cm^2, and in all but three (90%), it was within 0.2 cm^2 of the measured area of the value specimen (Fig. 3). Incorrect scan plane orientation relative to the minimal valve orifice opening may account for the imprecision found in two patients in whom the valve area was overestimated by >0.3 cm^2 (+0.4 cm^2 in both). In the study of Henry et al. (1), two-dimensional planimetry tended to underestimate the surgical areas. This underestimation was attributed to areas of





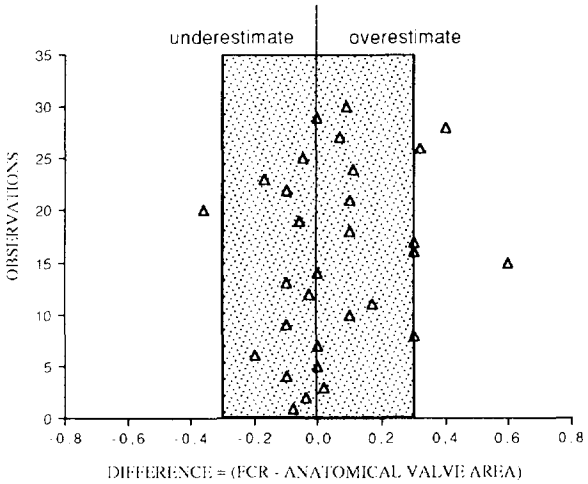


Figure 5. Left, Comparison between mitral valve areas measured by flow convergence region method and those measured in the corresponding valve specimen. **Right,** Differences between values of mitral valve areas measured by flow convergence region versus specimen valve areas. In three patients the difference is >0.3 cm^2 (toward overestimation).

calcification along the orifice margins, which increased the intensity of the returning echoes and thereby encroached on the orifice area. However, in our study group, the presence of calcifications did not significantly affect the reliability of the method. This reliability is probably due to the remarkable advances in machine and transducer technology made over the past 10 years. The sophisticated computer architecture and software-controlled image formation available in today's echocardiography machines have greatly improved image quality even in the presence of highly reflective echoes. Moreover, using the digital cine-loop memory and software calculation packages, it is possible to select individual frames directly from the digitalized images and to trace on-line measurements of the orifice areas without any significant loss of image quality.

Pressure half-time method and anatomic orifice. The results of the present study are consistent with the original hemodynamic concept that in patients with mitral stenosis, the rate of left atrial depressurization is inversely related to the narrowing of the anatomic orifice (16). Although other hemodynamic variables (namely left atrial and ventricular compliance and the initial atrioventricular pressure gradient) may affect the accuracy of the method in specific subsets of patients (17–20), in typical mitral stenosis (as in the present patient cohort), these variables tend to offset one another, thus leaving pressure half-time more purely dependent on anatomic obstruction (17).

The most important aspect of the present comparison is that the pressure half-time method tended to underestimate the anatomic orifice (Fig. 4). This tendency can be explained by the fact that the pressure half-time is dependent on the inflow resistance due to the funnel shape of the mitral apparatus as a whole, including both orifice and nonorifice components. The additional resistance within a stenotic conically shaped subvalvular apparatus may further slow the rate of pressure decline and, consequently, lead to a smaller calculated area than that delimited by the edges of the leaflets of the anatomic specimen.

Because two-dimensional planimetry actually measures the valve orifice delimited by the edges of the leaflets, whenever the valve area measured by the pressure half-time is significantly smaller than that measured by two-dimensional planimetry, the difference between the two values might represent the quantifiable contribution of the subvalvular apparatus to the obstruction. A recent case report seems to support this hypothesis (21).

PISA method and anatomic orifice. Our results showed good correlation between the PISA-determined valve areas and anatomic orifice size. In principle, the continuity equation predicts the valve area at the point where the velocity of the jet is highest. This region is situated immediately distal to, and is generally somewhat smaller than, the anatomic orifice ("vena contracta"). Some underestimation should therefore be expected. However, in previous studies (7,22) as well in ours, the method did not show systematic underestimation. On the contrary, in the present study the method tended to slightly overestimate the size of the anatomic orifice (Fig. 5). Technical reasons might explain this tendency. The low aliasing velocities relative to the Nyquist limit used in the present study cause a mild overestimation of the transmitral maximal flow rate and, consequently, an overestimation of the predicted area (7,22). Use of the simple leaflet angle correction factor ($\phi/180$) may also cause an overestimation of the area of the vena contracta area, as recently reported (23).

Flow area method and anatomic orifice. In our study, the flow area method underestimated the anatomic orifice size (Fig. 6). One possible interpretation of these results is that the outermost layers of the flow stream within a mitral funnel-shaped apparatus are greatly slowed by the friction forces acting at the fluid–solid interface. If the frequency Doppler shift originating from these slow-moving layers is below the high pass filter cutoff, they will be filtered out from the video

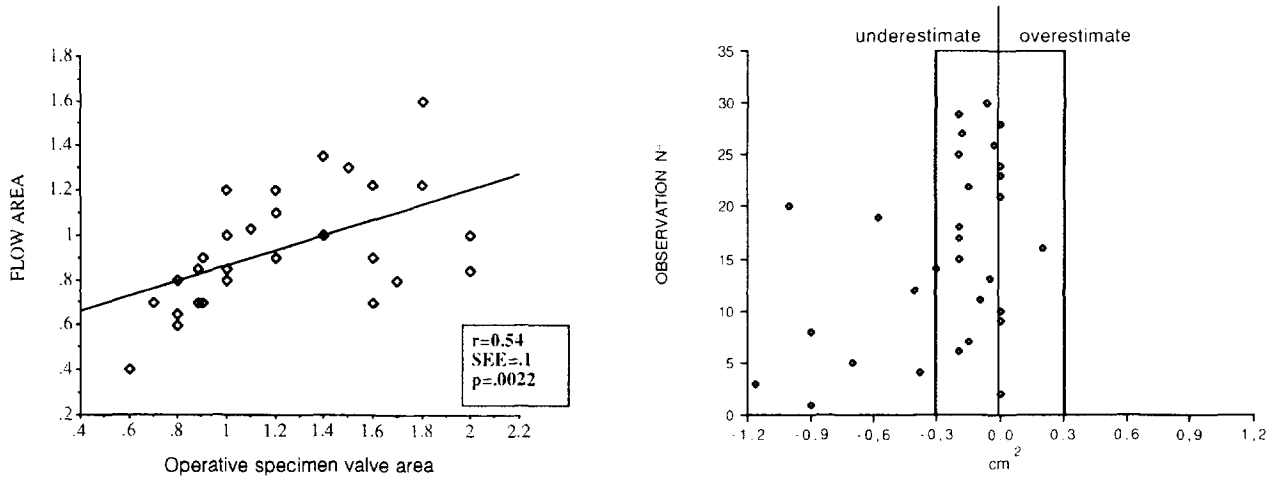


Figure 6. Left, Comparison between mitral valve areas measured by flow area method and those measured in the corresponding valve specimen. **Right,** Differences between values of mitral valve areas measured by flow area versus specimen valve areas. In eight patients the difference is >0.3 cm^2 (toward underestimation).

screen. As a result, the dimensions of the jet (and the calculated valve area) will be smaller than the corresponding anatomic orifice. The discrepancies with the results of Kawahara et al. (8), who reported excellent correlation between the mitral valve areas measured by the flow area method and those obtained at catheterization (r = 0.93, SEE 0.15 cm^2, p < 0.001), may be explained by the fact that the Gorlin formula used in their study as a reference standard reflects all the orifice and nonorifice phenomena encountered by the flow passing through the valve apparatus (14) and may therefore lead to a calculated valve area that is smaller than the orifice size delimited by the edges of the leaflets. Thus, the good correlation found may derive from the fact that both the flow area and the reference method underestimate the anatomic orifice. However, the flow area method is not routinely applied in our laboratory, and some discrepancies with regard to anatomic orifice may derive from the insufficient quality of our raw data rather than from the method itself.

Limits of the study. Whether the size of the orifice of the valve specimen, albeit accurately measured by a specifically designed sizer, represents the truest value for a beating heart is questionable. Changes in orifice area may occur with changes in cardiac output (24). However, this concept seems to be particularly applicable to stenoses with high transstenotic gradients and still pliable cusps (such as noncalcific aortic stenoses) rather than to mitral stenoses in which the average gradients are in the range of 10 to 25 mm Hg (24). In the present study, the sizer was firmly introduced into the orifice and, in all specimens, it fit the shape of the orifice completely (Fig. 1B). It is therefore unlikely that the maximal valve openings in vivo could have been significantly larger than those measured in the specimens. In addition, the sizer was not forced, and the commissures were not torn in any patient, making it similarly unlikely that the valve openings in vivo could have been significantly smaller than those measured in valve specimens. Finally, to avoid the effects of valve shrinkage, the measurements were made immediately after removal.

A second limitation of the present study was the inadequacy of the reference method for evaluation of subvalvular apparatus. We were not able to confirm (or reject) the hypothesis that the difference between planimetry and pressure half-time area may represent subvalvular stenosis. This study was not designed a priori for this aim, and the surgeons did not describe their visual assessment of the subvalvular apparatus according to a predefined semiquantitative score system; additional ad hoc studies are therefore needed.

Clinical implications. The present study offers some insights into the relations between mitral valve areas measured by four currently used two-dimensional and Doppler methods and corresponding anatomic orifice size. If we assume that any noninvasive method is reliable and clinically useful when it differs by no more than 0.3 cm^2 from the anatomic area (any greater discrepancies may affect decisions concerning patient management), two-dimensional planimetry remains the most

Table 2. Deviation From Anatomic Value in Patients With Mitral Stenosis Only and in Those With Associated Insufficiency*

	Δ 2D vs. AVA (cm^2)	Δ PHT vs. AVA (cm^2)	Δ FCR vs. AVA (cm^2)	Δ Flow Area vs. AVA (cm^2)
Mitral stenosis only (n = 19)	0.03 ± 0.12	−0.13 ± 0.29	0.06 ± 0.22	−0.22 ± 0.33
Associated mitral insufficiency (n = 11)	0.047 ± 0.14	−0.13 ± 0.16	0.04 ± 0.15	−0.36 ± 0.36

*p = NS for all comparisons. Data presented are mean value ± SD.

reliable method. Moreover, it does not involve the use of any assumptions, and in skilled hands, the internal orifice edges of even calcified valves can be accurately drawn. Failure to measure the valve orifice adequately by means of two-dimensional planimetry is primarily related to the body habitus: In the present study, this happened in three patients who were excluded from the analysis.

In "typical" cases of mitral stenosis, the pressure half-time method remains a valuable technical tool. The intriguing hypothesis that the difference in the valve measurements of two-dimensional planimetry and pressure half-time represents the quantifiable contribution of subvalvular obstruction may provide an impetus for additional studies. The transmitral Doppler spectrum also provides accurate measurements of transvalvular gradients, which are of great relevance for the comprehensive evaluation of mitral obstruction. Once a Doppler spectrum has been recorded, the calculation of mitral valve area by means of the pressure half-time is a very simple procedure; thus, the method should be routinely used in conjunction with two-dimensional planimetry.

Although technically demanding and time-consuming, the continuity equation applied to the flow convergence region may be considered a reliable alternative method. Conversely, we believe that the flow area method should be used with caution until its accuracy is better clarified by more extensive use.

Finally, although the presence of associated mild regurgitation did not affect the different degrees of precision of the various methods in the measurement of valve area, further investigations are needed to establish the effects of more severe mitral insufficiency.

References

1. Henry WL, Griffith JM, Michaelis LL, McIntosh CL, Morrow AG, Epstein SE. Measurement of mitral orifice area in patients with mitral valve disease by real-time, two-dimensional echocardiography. Circulation 1975;51:827–31.
2. Nichol PM, Gilbert BW, Kisslo JA. Two-dimensional echocardiographic assessment of mitral stenosis. Circulation 1977;55:120–8.
3. Wann LS, Weyman AE, Feigenbaum H, Dillon JC, Johnston KW, Eggleton RC. Determination of mitral valve area by cross-sectional echocardiography. Ann Intern Med 1978;88:337–41.
4. Martin RP, Rakowski H, Kleiman H, Beaver W, London E, Popp RL. Reliability and reproducibility of two dimensional echocardiographic measurement of stenotic mitral valve orifice area. Am J Cardiol 1979;43:560–8.
5. Hatle L, Angelsen B, Tromsdal A. Noninvasive assessment of atrioventricular pressure half time by Doppler ultrasound. Circulation 1979;60:1096–104.
6. Holen J, Aaslid R, Landmark K, Simonsen S. Determination of pressure gradient in mitral stenosis with a non-invasive ultrasound Doppler technique. Acta Med Scand 1976;199:445–60.
7. Rodriguez L, Thomas JD, Monterroso V, et al. Validation of the proximal flow convergence method. calculation of orifice area in patients with mitral stenosis. Circulation 1993;88:1157–65.
8. Kawahara T, Yamagishi M, Seo H, et al. Application of Doppler color flow imaging to determine valve area in mitral stenosis. J Am Coll Cardiol 1991;18:85–92.
9. Smith MD, Handshoe R, Handshoe S, Kwan OL, De Maria AN. 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. Circulation 1986;1:100–7.
10. Nakatani S, Masuyama T, Kodama K, Kitabatake A, Fujii K, Kamada T. Value and limitations of Doppler echocardiography in the quantification of stenotic mitral valve area: comparison of the pressure half-time and the continuity equation methods. Circulation 1988;1:78–85.
11. Gorlin R, Gorlin SG. Hydraulic formula for calculation of the area of the stenotic mitral valve, other cardiac valves, and central circulatory shunts. Am Heart J 1951;41:1–12.
12. Cohen MV, Gorlin R. Modified orifice equation for the calculation of mitral valve area. Am Heart J 1972;84:839–40.
13. Dumensnil JG, Yoganathan AP. Theoretical and practical differences between the Gorlin formula and the continuity equation for calculating aortic and mitral valve areas. Am J Cardiol 1991;67:1268–72.
14. Gorlin R. Calculations of cardiac valve stenosis: restoring an old concept for advanced applications. J Am Coll Cardiol 1987;10:920–2.
15. Ritcher HS. Mitral valve area: measurement soon after catheterization. Circulation 1963;28:451–4.
16. Libanoff AJ, Rodbard S. Atrioventricular pressure half-time: measure of mitral valve area. Circulation 1968;38:144–50.
17. Thomas JD, Wilkins GT, Choong CYP, et al. Inaccuracy of mitral pressure half-time immediately after percutaneous mitral valvulotomy: dependence on transmitral gradient and left atrial and ventricular compliance. Circulation 1988;78:980–93.
18. Thomas JD, Weyman AE. Doppler mitral pressure half-time: a clinical tool in search of theoretical justification. J Am Coll Cardiol 1987;10:923–9.
19. Chen C, Wang Y, Guo B, Lin Y. Reliability of the Doppler pressure half-time method for assessing effects of percutaneous mitral balloon valvuloplasty. J Am Coll Cardiol 1989;13:1309–13.
20. Flachskampf FA, Weyman AE, Gillam L, Chun-Ming L, Abascal VM, Thomas JD. Aortic regurgitation shortens Doppler pressure half-time in mitral stenosis: clinical evidence, in vitro simulation and theoretic analysis. J Am Coll Cardiol 1990;16:396–404.
21. Cohen JD, Sand ME, Sandelsky J, et al. Doppler echocardiographic evaluation of severe rheumatic submitral valve stenosis. J Am Soc Echocardiogr 1994;7:542–6.
22. Deng YB, Matsumoto M, Wang XF, et al. Estimation of mitral valve area in patients with mitral stenosis by flow convergence region method: selection of aliasing velocity. J Am Coll Cardiol 1994;24:683–9.
23. Rifking RD, Harper K, Tighe D. Comparison of proximal isovelocity surface area method with pressure half-time and planimetry in evaluation of mitral stenosis. J Am Coll Cardiol 1995;26:458–65.
24. Carabello BA. Advances in the hemodynamic assessment of stenotic cardiac valves. J Am Coll Cardiol 1987;10:912–9.