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Application of Doppler Color Flow Imaging to Determine Valve Area in Mitral Stenosis

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This study was undertaken to examine whether Doppler color flow imaging could accurately estimate the valve area in mitral stenosis. Doppler color flow assessments were performed in both an in vitro model and in 30 patients with mitral stenosis undergoing cardiac catheterization. In the experimental Doppler study using a circuit model, color jet width correlated well with actual orifice diameter (r = 0.99). In the clinical Doppler study, the mitral valve orifice was assumed to be elliptic and the mitral valve area was calculated from the following equation: $(\pi/4)(a \times b)$, where a = color jet width at the mitral valve orifice in the apical long-axis view (short diameter) and b = the width in the 90° rotated view (long diameter). Mitral valve area was also determined by two-dimensional echocardiography and the pressure half-time method, and the results for all three noninvasive methods were compared with those obtained at cardiac catheterization.

By Doppler color flow imaging, mitral valve area could be determined in all patients and there was a significant correlation between the Doppler jet and catheterization estimates of mitral valve area (r = 0.93). Valve area determined by two-dimensional echocardiography correlated well with catheterization measurements in 26 patients (r = 0.84). However, the area could not be determined in 4 (13%) of the 30 patients because of technical problems. Although there was a fair correlation between the valve area determined by the pressure half-time method and catheterization (r = 0.79), this method tended to overestimate valve area in patients with aortic regurgitation.

These findings suggest that Doppler color flow imaging can provide an accurate estimate of mitral valve area and appears to be potentially applicable to the assessment of the severity of mitral stenosis.

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Determination of mitral valve area is of clinical importance in assessing the severity of mitral stenosis because the valve area is not altered in various hemodynamic conditions (1,2). Measurement of mitral valve area from hemodynamic data obtained at cardiac catheterization (3,4) is generally accepted as the reference method, but it is invasive and therefore the performance of repeated study is difficult. Accordingly, the evaluation and follow-up of patients with mitral stenosis require a reliable noninvasive method for assessing mitral valve area.

Two-dimensional echocardiography is currently the most widely used method for quantifying mitral valve area (5–8). However, when the mitral valve is extensively distorted or severely calcified, accurate measurement of its area by this method may not be feasible (5–8). Moreover, two-dimensional echocardiography is highly dependent on optimal technique, both in achieving the proper gain settings and in locating the true mitral orifice in the short-axis view (7,8). The pressure half-time method proposed by Hatle et al. (9,10) has also gained widespread acceptance as a noninvasive form of assessing mitral valve area. However, several reports (11–16) have indicated that this method cannot accurately estimate the mitral valve area in the presence of aortic regurgitation and left ventricular dysfunction.

Recent investigations have demonstrated that Doppler color flow imaging allows estimation of the severity of the stenotic lesion (17–20) and the size of the defect (21) in the cardiovascular system. Some reports (22,23) have indicated that the width of the central laminar core just at the orifice corresponds to the actual orifice diameter. Therefore, accurate measurement of the width of the color jet passing through the mitral valve orifice may provide quantitative assessment of the severity of mitral stenosis. However, no reported study has systematically examined the accuracy of Doppler color flow imaging in determining mitral valve area.

In the present study, we examined whether Doppler color flow imaging could provide an accurate estimate of the valve area in mitral stenosis. First, the reliability of this method for measuring jet width was studied in an experimental model. Second, we compared the Doppler color jet-derived valve areas with those obtained by the conventional noninvasive methods of two-dimensional echocardiography and the pres-

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JACC Vol. 18, No. 1
July 1991:85–92

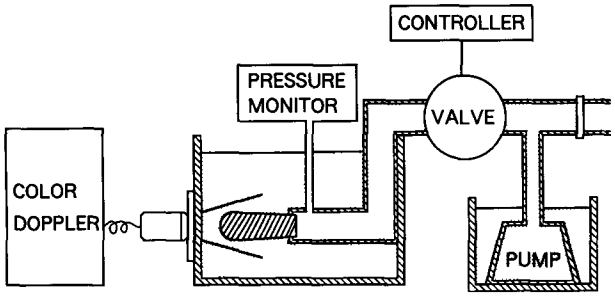

Figure 1. Diagram of the in vitro circuit model used to examine the accuracy of measurement of the color jet width. Glycerin solution containing sephadex (at a viscosity of 3.8 centipoise, similar to the viscosity of blood) was rhythmically squirted into a water bath as a jet through an exchangeable circular sharp-edged orifice with a cross-sectional diameter of 4 to 16 mm. An open-shut valve and a pumping system were used to produce the pulsatile flow. Driving pressure, ejection time and pulse rate were controllable and were set at 10 mm Hg, 500 ms and 60/min, respectively. The jet was imaged with use of a Toshiba SSH-160A system with a 2.5 MHz transducer. The transducer was placed parallel to the jet. The distance between the transducer and the orifice was set at 7 cm.

sure half-time method, using cardiac catheterization data as the reference standard.

Methods

Experimental Study

Experimental apparatus. It was initially necessary to examine whether the width of the color jet at the valve orifice could represent the actual diameter of the orifice. A circuit model was used to measure the width of the flow jet by Doppler color flow imaging (Fig. 1). Glycerin solution containing sephadex (at a viscosity of 3.8 centipoise, similar to the viscosity of blood) was rhythmically squirted into a water bath as a jet through a circular and sharp-edged orifice with a cross-sectional diameter of 4 to 16 mm.

The driving pressure was 10 mm Hg, the ejection time 500 ms and the rate at which the jets were delivered 60/min. Each jet was examined with a Toshiba SSH-160A system using a 2.5 MHz phased array transducer. Flow velocities were superimposed on the two-dimensional image in 32 shades of red or blue, representing flow toward or away from the transducer, respectively. The pulse repetition frequency was set at 4.5 kHz and the color filter was set at its highest level to exclude low velocity eddies that often occur around the central core of a jet. This high pass filter rejected velocities <0.37 m/s. Color gain was standardized by starting at maximal gain and then adjusting the gain downward until some background noise just disappeared.

To obtain high quality color images, the number of scan lines and the frequency of the ultrasonic interrogating bursts per scan line were increased. The frame rate achievable with an instrument is dependent on the angle of the sector arc, pulse repetition frequency, line density and frequency of bursts per scan line (24). By the use of increased line density and multiple bursts, a long data acquisition period for each frame then becomes necessary (24). Therefore, each examination was performed using the narrowest sector angle (a sector arc of 30°) capable of displaying a flow jet at the orifice. Line density was set at 30 lines/frame at this sector arc. The frame rate in these settings was 10 frames/s and the frequency of bursts per scan line was calculated from these variables.

Experimental procedure. The transducer was placed parallel to the flow jet and a damper was used to obtain the same decrement of the Doppler signal that occurs during imaging in patients. The distance between the transducer and the orifice was set at 7 cm, and the transducer was moved and angled to obtain the clearest color jet. Orifice diameter was varied from 4 to 16 mm in 2 mm steps, and the color jet width for each orifice was defined as the width of the color signal appearing through the hole. Jet width data were recorded as the mean value of five measurements and were compared with the actual diameters.

Clinical Study

Study patients. In our hospital, all clinical studies including the present one are controlled by the Hospital Medical Ethics Committee. All patients in the present study gave informed consent. From April 1988 to March 1989, a total of 49 consecutive patients with native mitral valve stenosis were examined by both Doppler color flow imaging and cardiac catheterization. Nineteen patients with moderate or severe mitral regurgitation demonstrated by Doppler color flow imaging were excluded. The remaining 30 patients formed the study group. Their ages ranged from 24 to 70 years (mean 50.3); there were 9 men and 21 women. Eleven patients were in sinus rhythm and 19 had atrial fibrillation at the time of the study. Twelve patients had associated aortic regurgitation demonstrated by aortic root angiography and seven had moderate or severe tricuspid regurgitation demonstrated by Doppler examination. Ultrasound examination was performed 1 to 7 days before cardiac catheterization in all patients.

Doppler color flow imaging. Color flow examinations were performed with the same Doppler echocardiographic apparatus used in the experimental study. The pulse repetition frequency, high pass filter, line density, number of bursts per scan line and color gain were the same as in the experimental study. The two-dimensional gain was adjusted downward so that visualization of the cardiac structures was just possible because excessive gain on the anatomic image can obscure flow on the color display (25) and lead to underestimation of the width of the stenosis jet at the valve orifice. Thus, both the color gain and the two-dimensional gain were set for individual patients.

The shape of the mitral valve orifice was observed in the parasternal short-axis view, after which the transducer was moved to the cardiac apex and transmitral flow was monitored from the apical window. Because the mitral stenosis jet

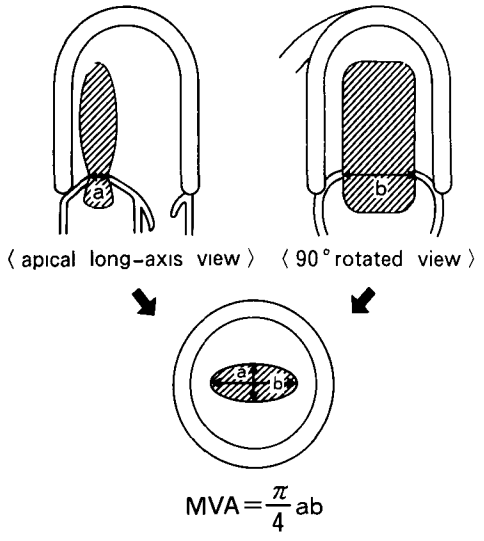

Figure 2. Diagram of the method used to calculate mitral valve area (MVA) by Doppler color flow imaging. **Upper left,** The width of color jet at the mitral valve orifice in the apical long-axis view was defined as the short diameter of an ellipse (a) representing the valve orifice. **Upper right,** The width of the color jet in the 90° rotated view was defined as the long diameter of the ellipse (b). The mitral valve area was then calculated from the equation for the area of an ellipse (MVA = [π/4][a × b]).

is usually directed toward the left ventricular apex, the apical plane provides the best view to obtain clear color signals of the jet by parallel alignment of the Doppler beam with the flow. First, the width of the color jet at the mitral valve orifice was measured in the apical long-axis view during early diastole, and this was defined as the short diameter (a) of the ellipse forming the valve orifice. The mitral stenosis jet frequently converged at the tips of the mitral valve leaflets in this view, so particular care was taken to measure this convergent site of the jet at the valve. Second, the transducer was rotated clockwise about 90° and the mitral stenosis jet was again observed. The transducer was positioned meticulously to obtain the color jet representing the long diameter (b) of the ellipse. Mitral valve area was then calculated by applying the equation for the area of an ellipse: (π/4)(a × b) (Fig. 2). The color jet diameters were measured by computer analysis and the mean value of five beats was recorded.

Two-dimensional echocardiography. Two-dimensional echocardiograms of the mitral valve were obtained in the standard parasternal short-axis view (5,6), and the smallest orifice of the mitral valve was carefully identified by scanning from the left atrium to the left ventricular apex. Echo gain was adjusted to the lowest level that permitted visualization of the entire circumference of the mitral valve orifice (5,6). After visualization of the orifice at its maximal opening in early diastole, mitral valve area was calculated by planimetry and was determined as the mean value of five beats.

Pressure half-time method. A continuous wave Doppler study was also used to determine mitral valve area. After the transducer was placed at the cardiac apex, the maximal velocity shift of mitral inflow was sought by adjusting the direction and portion of the Doppler beam. The angle between the beam and the estimated direction of mitral inflow was minimized to attain the highest peak velocity. Doppler signals were recorded on a strip chart system at a paper speed of 50 mm/s after fast Fourier transformation analysis. All measurements were made from the outer border of the spectral envelope. The early diastolic velocity was identified and divided by $\sqrt{2}$ to determine the velocity corresponding to half the initial pressure gradient, and the time between these two points was taken as the pressure half-time. Mitral valve area was then calculated by dividing 220 by the pressure half-time (9,10). This determination was made from the analysis of five high quality signals in the patients in sinus rhythm. In patients with atrial fibrillation, seven signals were measured from cardiac cycles with a sufficiently long RR interval to allow the identification of transmitral velocity decay.

Cardiac catheterization. A 7F Swan-Ganz thermodilution catheter was used to record pulmonary artery wedge pressure and determine cardiac output; a 5F high flow pigtail catheter was used to record left ventricular pressure. The mean diastolic transmitral pressure gradient was calculated with computer assistance (Hewlett-Packard 5600M) from the left ventricular and pulmonary artery wedge pressures, which were simultaneously recorded with a standard fluid-filled manometer system. Cardiac output was determined by thermodilution in the 23 patients without tricuspid regurgitation and by the Fick method in the 7 patients with moderate or severe tricuspid regurgitation. Cardiac output by thermodilution was measured as the mean value of three injections of iced saline solution. Mitral valve area was calculated from cardiac output and the mean diastolic transmitral pressure gradient using the Gorlin formula (3,4).

Left ventriculography was performed in all patients. Aortic root angiography was performed in the patients with clinically suspected aortic regurgitation. The severity of aortic regurgitation was graded using established criteria (26) as follows: grade 1 (four patients), grade 2 (six patients), grade 3 (two patients) and grade 4 (none).

Interobserver variability of Doppler color flow imaging. To test the reliability of the Doppler color flow imaging method, 10 randomly selected patients were examined by another observer without knowledge of previous findings. Mitral valve area was determined by two independent observers who did not know each other's results or the cardiac catheterization data. Pulse repetition frequency, line density, number of bursts per scan line and sector arc were the same for the two studies. Color gain was individually set for each patient in both examinations. The correlation coefficient obtained between these two studies was 0.98 ($y = 1.15x - 0.16$). Thus, interobserver variability was not significantly different.

Statistical analysis. All values were expressed as mean values ± SD. Simple linear regression analysis was used to

JACC Vol. 18, No. 1
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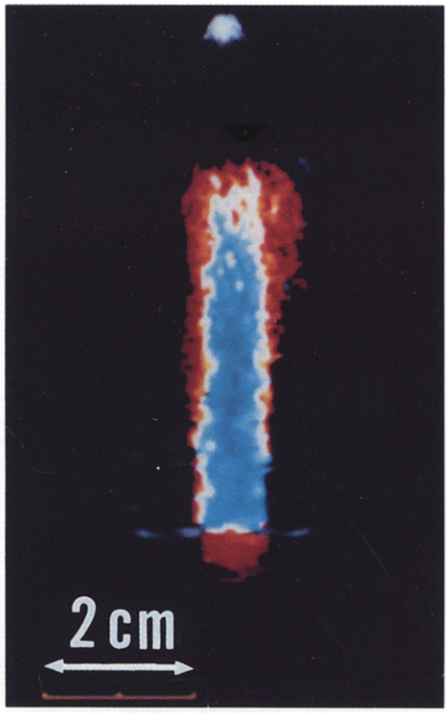

Figure 3. Visualization of the color jet in the experimental study. Although the flow jet tended to widen considerably distal to the orifice, a clear blue image representing a laminar central core of aliasing was obtained at the orifice, without eddies. The color jet width of this orifice was 9.7 mm; the actual diameter was 10 mm.

compare the color jet width and the actual orifice diameter in the experimental study, as well as to compare Doppler color flow imaging, two-dimensional echocardiography and the pressure half-time method with cardiac catheterization.

Results

Experimental Study

The edge of the color jet was linear at its orifice and could be clearly distinguished from the circumference. Although the flow jet tended to widen farther away from the orifice, a clear color image in blue, which represented the laminar core, was obtained at the orifice without eddies (Fig. 3). The width of color jet at the orifice correlated extremely well with its actual diameter ($r = 0.99$; $y = 0.93x + 0.62$, standard error of the estimate [SEE] = 0.2 mm; $p < 0.001$). The mean absolute difference between the color jet width and actual diameter was 0.3 ± 0.1 mm.

Clinical Study

The clinical data and mitral valve areas of the 30 patients with mitral stenosis are shown in Table 1.

Doppler color flow imaging. The mitral valve orifice in the parasternal short-axis view appeared to be severely deformed in 3 patients; it was elliptic with only slight deformity in the remaining 27 patients. A color flow jet through the stenotic mitral valve was observed through the apical win-

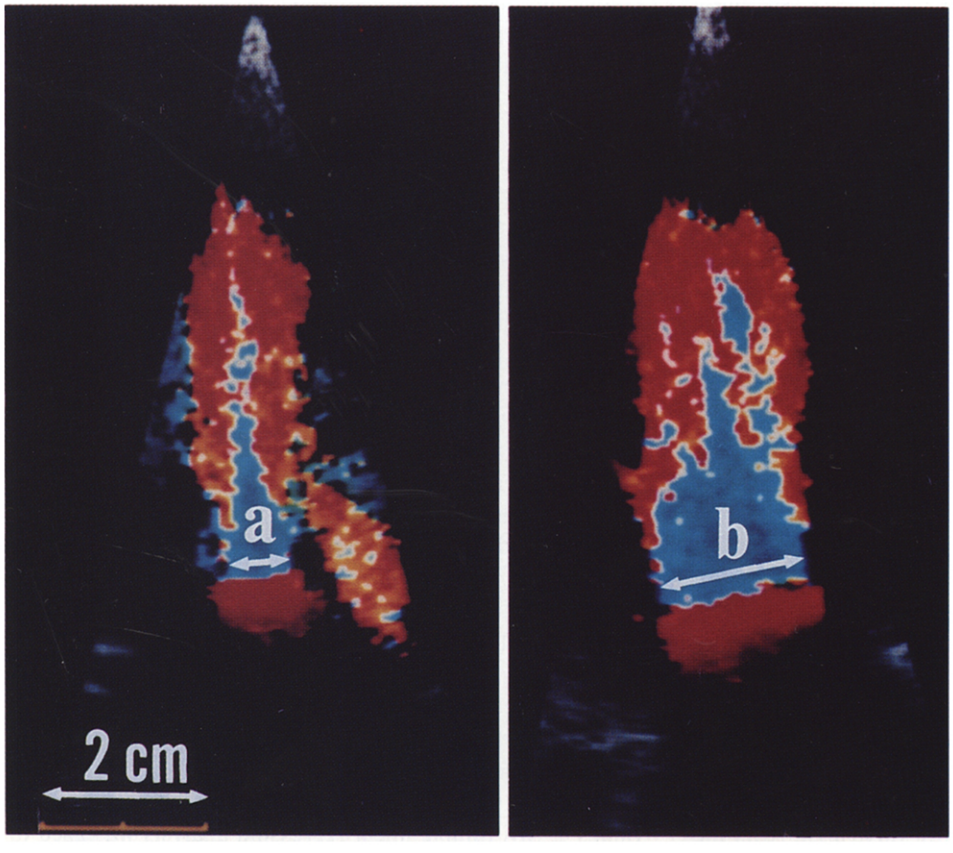

Figure 4. Visualization of mitral stenosis jets from the apical window and the measurement of mitral valve area. **Left,** Width of the mitral stenosis jet in the apical long-axis view (that is, the short diameter of the ellipse [a] representing the valve orifice) was 0.8 cm. In this view, convergence of the stenosis jet at the tips of the valve leaflets was observed. Although an aortic regurgitant jet was observed in this case, the mitral stenosis jet was easily distinguished from it at the mitral valve leaflets. **Right,** Width of the mitral stenosis jet in the 90° rotated view (the long diameter of the ellipse [b]) was 1.9 cm. In this view, no convergence was observed and the edge of the mitral stenosis jet was straight. Mitral valve area calculated in this case was 1.2 cm^2 compared with 1.3 cm^2 determined by cardiac catheterization.

Table 1. Clinical Data, Mitral Valve Area and Color Jet Width in 30 Patients With Mitral Stenosis

Pt No.	Age (yr)/ Gender	Rhythm	AR (grade)	MVA (cm^2)				Jet Width (mm)	
				Cath	Color	2DE	PHT	Sd	Ld
1	48/M	AF	–	0.60	0.43	0.93	0.57	6.1	9.0
2	24/F	SR	–	0.74	0.81	0.64	0.92	6.0	17.2
3	68/F	AF	+ (2)	0.92	0.97	1.16	1.00	7.5	16.4
4	59/F	AF	+ (1)	1.26	1.20	1.35	1.00	7.9	19.3
5	70/M	AF	–	1.25	1.33	1.20	0.82	8.2	20.7
6	62/F	AF	–	0.55	0.60	0.76	0.68	5.7	13.4
7	44/F	SR	+ (1)	0.90	0.87	0.90	1.02	8.4	13.2
8	61/F	AF	–	1.16	1.18	1.15	1.10	9.5	15.8
9	55/F	AF	–	1.02	0.99	1.14	0.78	7.2	17.5
10	38/F	SR	+ (2)	1.10	1.00	1.15	1.22	7.4	17.2
11	57/F	AF	–	1.02	0.96	0.84	0.62	6.2	19.7
12	44/F	SR	–	2.30	2.11	*	1.70	14.3	18.8
13	42/M	AF	+ (3)	0.94	0.89	0.88	1.21	6.6	17.2
14	44/F	AF	+ (2)	0.91	0.81	0.82	0.88	5.7	18.1
15	44/F	AF	–	1.45	1.62	1.48	1.02	10.7	20.6
16	42/M	AF	–	2.04	2.03	2.28	1.65	11.7	22.1
17	67/F	AF	+ (1)	0.80	0.74	0.91	0.88	6.4	14.7
18	41/F	SR	–	0.98	0.92	*	1.01	9.0	13.0
19	44/F	SR	–	1.30	1.41	*	1.00	9.3	19.3
20	36/M	AF	–	0.66	0.58	0.79	0.55	6.5	11.4
21	50/M	SR	–	0.57	0.60	*	0.63	6.7	11.4
22	62/M	AF	+ (2)	0.80	0.91	0.90	0.85	6.3	18.4
23	59/F	AF	+ (2)	1.00	1.14	1.61	1.10	9.0	16.1
24	48/F	SR	+ (3)	0.70	0.82	0.76	0.96	7.4	14.1
25	46/F	SR	–	1.08	1.04	1.30	1.17	7.2	18.4
26	43/M	AF	–	1.53	1.68	1.40	1.10	9.1	23.5
27	58/F	AF	+ (2)	1.08	1.40	0.94	1.10	9.9	18.0
28	68/F	SR	+ (1)	0.97	1.00	0.70	1.20	5.3	24.0
29	57/M	AF	–	1.45	1.92	1.26	1.29	11.5	21.3
30	27/F	SR	–	0.80	1.20	0.69	0.66	9.7	15.8
Mean	50.3			1.06	1.10	1.10	0.99	8.1	17.2
SD	11.9			0.40	0.43	0.36	0.27	2.1	3.6

*Not determined; AF = atrial fibrillation; AR = aortic regurgitation; Cath = cardiac catheterization; Color = Doppler color flow imaging; F = female; Ld = long diameter; M = male; MVA = mitral valve area; PHT = pressure half-time; Pt = patient; Sd = short diameter; SR = sinus rhythm; 2DE = two-dimensional echocardiography; + = present; – = absent.

dow in all patients (Fig. 4). The angle between the Doppler beam and the direction of the mitral stenosis jet was <20° in all patients. Although the stenosis jet widened shortly after the orifice and showed increasing turbulence more distal to the valve, a central laminar core without eddies or turbulence was observed just at the orifice, and accurate measurement of the jet width was possible at this level. Although convergence of the mitral stenosis jet was observed at the tips of the mitral valve leaflets in the apical long-axis view, no convergence was present in the 90° rotated view. Even in patients with associated aortic regurgitation, the mitral stenosis jet could be clearly distinguished from the aortic regurgitant jet at the mitral orifice.

The width of the color jet in the apical long-axis view, which represents the short diameter of the ellipse used to determine valve area, ranged from 5.3 to 14.3 mm (mean 8.1 ± 2.1), whereas the long diameter ranged from 9 to 24 mm (mean 17.2 ± 3.6). Thus, mitral valve area determined by Doppler color flow imaging ranged from 0.43 to 2.11 cm^2 (mean 1.10 ± 0.43). These values correlated well with the results of cardiac catheterization (range 0.55 to 2.30 cm^2; mean 1.06 ± 0.40), with a correlation coefficient of 0.93 ($y = 0.98x + 0.05$, $n = 30$, SEE = 0.15 cm^2; $p < 0.001$) (Fig. 5). The mean absolute difference between the catheterization and Doppler color flow estimates of valve area was 0.11 ± 0.11 cm^2. The correlation coefficient was 0.94 in sinus rhythm and 0.95 in atrial fibrillation. However, Doppler color flow imaging overestimated the area as shown by catheterization by about 0.3 cm^2 in three patients (Patients 27, 29 and 30) who had a markedly deformed mitral valve orifice.

Conventional noninvasive methods. Clear images of the mitral valve orifice were obtained in 26 of the 30 patients examined by two-dimensional echocardiography. Mean mitral valve area was 1.10 ± 0.36 cm^2 (range 0.64 to 2.28) and these values correlated well with cardiac catheterization data ($r = 0.84$; $y = 0.93x + 0.12$, $n = 26$, SEE = 0.19 cm^2; $p < 0.001$) (Fig. 6). The mean absolute difference between

JACC Vol. 18, No. 1
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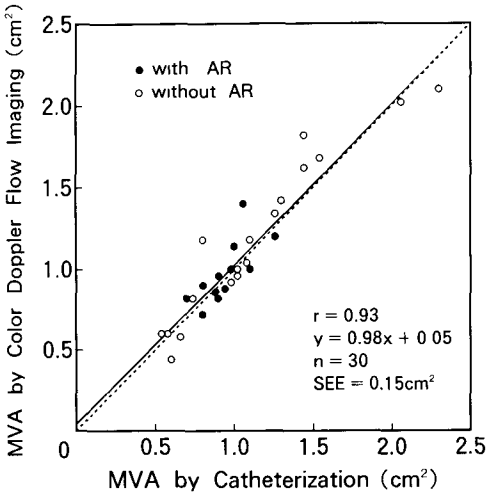

Figure 5. Mitral valve areas (MVA) determined by Doppler color flow imaging plotted against the cardiac catheterization data. **Closed circles** represent patients with and **open circles** patients without aortic regurgitation (AR). The correlation coefficient for this relation was 0.93 in 30 patients.

valve area determined by catheterization and two-dimensional echocardiography was 0.15 ± 0.12 cm^2. However, mitral valve area could not be determined by echocardiography in four patients (13%) because of technical problems. In one of the four (Patient 18), the mitral valve orifice was not adequately visualized in the parasternal short-axis view because the ultrasound beam could not be directed perpendicular to the valve itself. In Patients 12 and 19 the entire mitral valve orifice could not be depicted in one image in the short-axis view because of the large size of the orifice; in Patient 21 the presence of severe calcification of the valve leaflets resulted in poor visualization of the orifice.

Mean mitral valve area determined by the pressure half-time method was 0.99 ± 0.27 cm^2 (range 0.55 to 1.70) and correlated less well with cardiac catheterization data (r = 0.79; y = 0.56x + 0.40, n = 30, SEE = 0.17 cm^2; $p < 0.001$) (Fig. 6). The mean absolute difference between valve area determined by cardiac catheterization and the pressure half-time method was 0.19 ± 0.15 cm^2 and this method tended to overestimate mitral valve area in patients with aortic regurgitation, as previously reported (11,12).

Discussion

Conventional methods for determining mitral valve area. Noninvasive measurement of valve area in mitral stenosis has been performed mainly by tracing the two-dimensional image of the valve orifice (5–8) or by the pressure half-time method derived from Doppler measurement of the transmitral flow velocity (8–10). Although these methods have gained widespread acceptance, several shortcomings remain.

In determining mitral valve area by two-dimensional echocardiography, several reports (5,6) have indicated that two-dimensional scanning at high gain settings may underestimate the true area as a result of a "blooming" effect from the thickened valve leaflets. Conversely, low gain settings may lead to image dropout and provide a falsely large estimate of orifice size (7). Overestimation can also occur if the parasternal short-axis view is not obtained perpendicular to the valve itself. In addition, accurate tracing of the valve orifice is sometimes difficult in patients with a distorted, thickened or calcified mitral valve (5–8). In the present study, 13% of the patients had technically inadequate two-dimensional images of the valve orifice, a result similar to that previously reported by others (5–8).

The pressure half-time method has been reported (11,12)

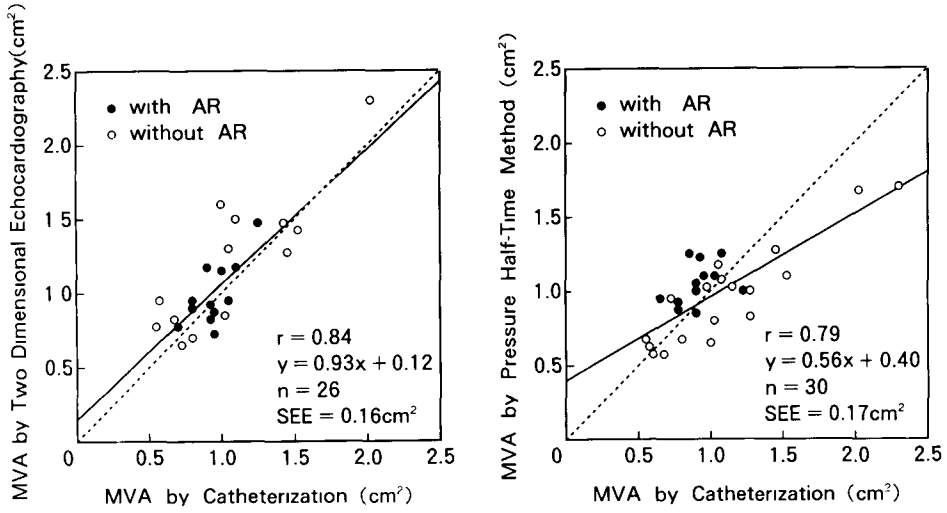

Figure 6. Mitral valve area (MVA) determined by two-dimensional echocardiography (**left**) and the pressure half-time method (**right**) is plotted against cardiac catheterization data. **Closed circles** represent patients with and **open circles** represent patients without aortic regurgitation (AR). **Left,** The correlation between mitral valve area determined by two-dimensional echocardiography and cardiac catheterization data was r = 0.84 in 26 of the 30 patients. Valve area could not be determined by two-dimensional echocardiography in four patients because of technical problems. **Right,** The correlation between mitral valve area determined by the pressure half-time method and cardiac catheterization data was r = 0.79 in 30 patients. The pressure half-time method overestimated valve area in patients with aortic regurgitation.

to overestimate mitral valve area in the presence of aortic regurgitation, as was found in the present study. The effect of aortic regurgitation on pressure half-time may be explained by a steep increase in left ventricular diastolic pressure and hence a rapid reduction in the transmitral pressure gradient. Another possible explanation is that the aortic regurgitant jet might interfere with the mitral stenosis jet and so produce overestimation of mitral valve area (11,12). Furthermore, it has been reported that the pressure half-time method cannot provide an accurate estimate of mitral valve area in patients with cardiac failure (11,13) or after mitral valvotomy (14,15).

Previous studies. Measurement of the Doppler color jet width has been used to estimate the severity of stenotic lesions in the cardiovascular system. Simpson et al. (18) demonstrated that in coarctation of the aorta, the color jet width in the region of coarctation correlated well with the coarctation diameter measured at angiography and indicated that Doppler color flow imaging could quantify the severity of the coarctation. Fan et al. (17) showed that the width of the aortic stenosis jet correlated well with aortic valve area determined by cardiac catheterization, and reflected the severity of aortic stenosis. In this context, Doppler color flow imaging might be also applicable in assessing the severity of mitral stenosis. However, systematic examination of the Doppler color jet assessment of mitral valve area has been reported only in preliminary data (19,20).

Validity and advantages of the present method. In the experimental study, the width of the laminar central core at the orifice correlated significantly with the actual orifice diameter, suggesting that this method is reliable in determining the diameter of an orifice. In the clinical study, mitral valve area calculated from the width of the laminar central core of the stenosis jet showed a good correlation with that determined by cardiac catheterization. These results indicate that the present method has potential clinical utility for the quantitative assessment of the severity of mitral stenosis.

The mitral stenosis jet was imaged in the apical instead of the parasternal view. This view is the most suitable for accurately measuring the width of the mitral stenosis jet because the Doppler beam can be fixed nearly parallel to the direction of the flow. Moreover, we imaged the mitral stenosis jet from two orthogonal apical views and calculated the valve area itself using the ellipse equation. Measurement of jet width from a single plane may not be satisfactory to calculate valve area in mitral stenosis because the valve orifice cannot be similarly circular. In addition to these approaches, the use of increased line density and multiple bursts, respectively, led to the enhancement of lateral resolution and improvement of the signal to noise ratio (24) and would contribute to the accurate measurement of the jet width.

With Doppler color flow imaging, valve area could be determined even in patients who had inadequate two-dimensional images of the orifice in the parasternal short-axis view. This may be one advantage of the present method. In addition, this method could readily separate the mitral stenosis jet from the aortic regurgitant jet at the mitral valve orifice. Thus, another advantage is that this method provides an accurate estimate of valve area even in the presence of aortic regurgitation and perhaps left ventricular dysfunction, which are often associated with mitral stenosis and affect the results of the pressure half-time method (11–16). Therefore, Doppler color flow imaging may be helpful for determining mitral valve area in patients in whom conventional methods are not applicable because of anatomic or hemodynamic problems.

Clinical implications. Measurement of mitral valve area is also important in estimating the effects of balloon mitral valvuloplasty, a relatively new therapeutic technique for mitral stenosis. With two-dimensional echocardiography, the visualization of the entire valve orifice may be difficult at one slice of the short-axis view because of wide splitting of commissures after the procedure. It has been reported (14,15) that the pressure half-time method cannot provide an accurate estimate of valve area immediately after mitral valvuloplasty because of the associated rapid changes in left ventricular and atrial compliance. Under these conditions, Doppler color flow imaging may become an alternative method for evaluating the extent of the increase in mitral valve area immediately after this procedure.

Limitations. Several limitations to this technique must be considered. 1) The stenotic mitral valve orifice is not necessarily elliptic in some patients. Indeed, the Doppler color flow imaging method overestimated the catheterization-determined valve area by about 0.3 cm^2 in three patients with a severely deformed mitral valve orifice. These patients may need to be assessed using other techniques. However, Doppler color flow imaging appears to be reliable in patients with minor valvular deformity because the orifice is still almost elliptic. 2) The Doppler and cardiac catheterization studies were not performed simultaneously in our patients. However, the impact of nonsimultaneous data acquisition on the measurement of valve area is thought to be minimal because valve area is less subject to marked variations. 3) Doppler color flow assessment is known to be instrument dependent (27). However, the technique of increased line density and multiple bursts to obtain high quality images does not require any special arrangement of commercially available equipment. Therefore, one can corroborate the present method with the use of other Doppler color flow equipment.

Conclusions. Doppler color flow imaging allows the accurate estimation of stenotic mitral valve area and has some advantages over conventional noninvasive methods. Doppler color flow imaging settings on the variety of commercially available equipment should be standardized and the method subjected to further clinical investigation.

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