Comparison of Vena Contracta Width by Multiplane Transesophageal Echocardiography With Quantitative Doppler Assessment of Mitral Regurgitation

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Mitral regurgitation (MR) severity is routinely assessed by Doppler color flow mapping, which is subject to technical and hemodynamic variables. Vena contracta width may be less influenced by hemodynamic variables and has previously been shown to correlate with angiographic estimates of MR severity. This study was performed to compare mitral vena contracta width by multiplane transesophageal echocardiography (TEE) with simultaneous quantitative Doppler echocardiography in 35 patients with MR. The vena contracta width was measured at the narrowest portion of the MR jet as it emerged through the coaptation of the leaflets; it was identified in 97% of the patients. Vena contracta width correlated well with regurgitant volume ($R^2 = 0.81$) and regurgitant orifice area ($R^2 = 0.81$) by quantitative Doppler technique. A vena contracta width ≥0.5 cm always predicted a regurgitant volume >60 ml and an effective regurgitant orifice area ≥0.4 cm^2 in all patients. A vena contracta width ≤0.3 cm always predicted a regurgitant volume <45 ml and a regurgitant orifice area ≤0.35 cm^2. Thus, vena contracta width by multiplane TEE correlates well with mitral regurgitant volume and regurgitant orifice area by quantitative Doppler echocardiography and provides a simple method for the identification of patients with severe MR. ©1998 by Excerpta Medica, Inc.

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The severity of mitral regurgitation (MR) is often evaluated noninvasively by Doppler color flow mapping of the jet area within the left atrium.[1,2] However, the jet area is influenced by a number of technical and hemodynamic variables.[3,4] An alternative method using proximal flow convergence has been reported to quantitatively measure regurgitant stroke volume, flow rate, and orifice area.[5] This method may overestimate the degree of MR with eccentric jets, and requires geometric assumptions that do not account for dynamic changes in the orifice.[6,7] Regurgitant orifice area has been proposed as a reliable index of the severity of valvular regurgitation.[8] It can be assessed indirectly by measuring the width of the vena contracta of a color Doppler jet as it emerges from the regurgitant orifice.[9] The vena contracta is defined as the narrowest cross-sectional area of a jet and has been shown to be independent of hemodynamic variations in vitro.[10] In vivo studies have shown that vena contracta width correlates well with angiographic and quantitative Doppler estimates of regurgitant volumes.[11–14] However, vena contracta width may less accurately represent an asymmetric orifice if measured in a single-imaging plane.[15–17] This study was performed to assess the accuracy of mapping the vena contracta width by multiplane transesophageal echocardiography (TEE) compared with quantitative Doppler estimates of regurgitant volume and regurgitant orifice area.

METHODS

Patient group: We prospectively studied 35 patients with MR who were referred for TEE at Parkland Memorial Hospital (n = 24) or the Dallas VA Medical Center (n = 11). Patients were excluded from the study if they had aortic regurgitation or stenosis, significant mitral stenosis, acute myocardial infarction, and a mechanical or bioprosthetic valve. Of the 36 patients who were initially enrolled, only 1 patient was excluded due to inability to measure the mitral or aortic annulus. Patients ranged in age from 23 to 80 years (mean 54 ± 13). There were 23 men and 13 women. Etiology of MR was mitral valve prolapse in 16, active infective endocarditis in 4, coronary artery disease in 5, rheumatic disease in 1, dilated cardiomyopathy in 4, and uncertain etiology in 5. Atrial fibrillation was present in 7 patients during the study.

Transesophageal echocardiography: TEE was performed using a 5-MHz multiplane probe (Hewlett Packard 2500, Andover Massachusetts, or Vingmed 800C, Harten, Norway) that enables rotation of the imaging plane from a standard transverse position (0°) through all intermediate angles to a reversed horizontal position (180°). This probe acquires Doppler color flow images at a frequency of 4 MHz. For each patient, color flow gain settings were adjusted down-

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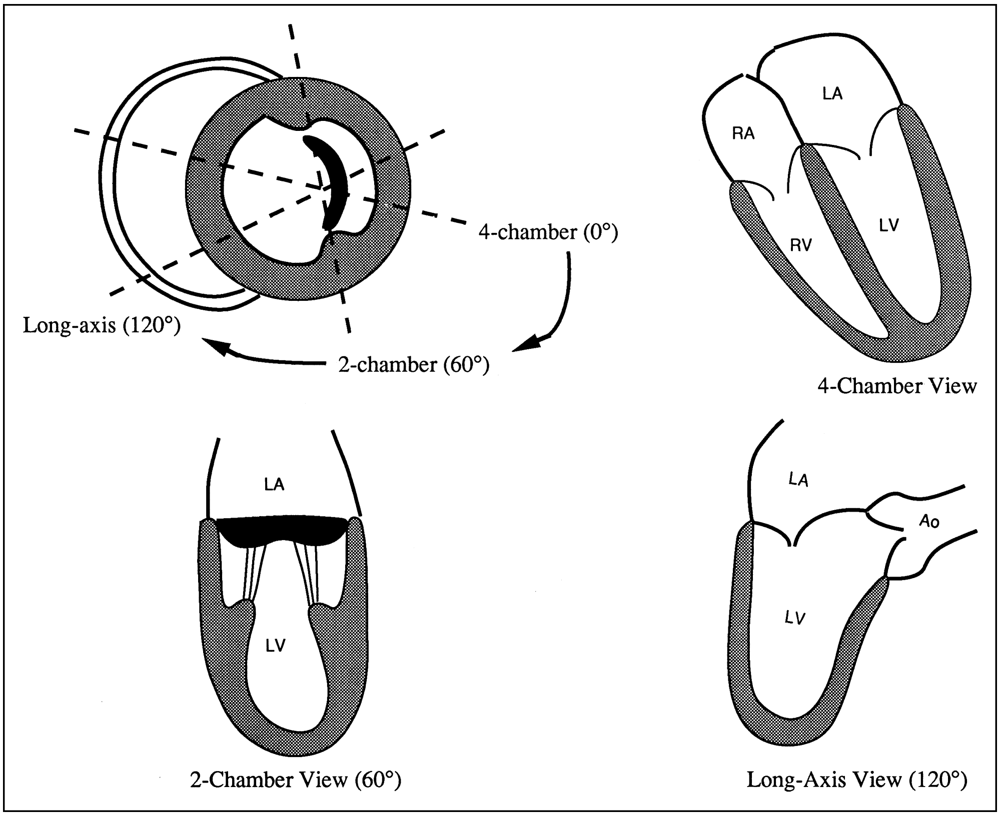

FIGURE 1. The relation between TEE imaging planes and the mitral apparatus. The *dotted lines* in the short-axis view show the angles at which the 2-chamber, 4-chamber, and long-axis planes intersect mitral leaflet coaptation. TEE images depict the 4-chamber view, which is tangential to leaflet coaptation, the 2-chamber view, which is parallel to leaflet coaptation, and the long-axis view, which is perpendicular to leaflet coaptation.

ward to the point at which background noise disappeared; the settings were maintained at that level.

Initially, monoplane TEE was used by keeping the imaging plane fixed in the transverse position (0°). The probe tip was manipulated (by rotation as well as anteroposterior and lateral flexion) to optimally image the vena contracta of the MR jet from the 4-chamber view. Afterward, the scanplane was freely rotated through a complete 180° arc to fully image the mitral apparatus. Long-axis and 2-chamber views were obtained with orientation orthogonal to leaflet coaptation (Figure 1).[18] This was executed by first rotating the scanplane (30° to 60°) to obtain a 2-chamber view that showed both papillary muscles and was therefore parallel to leaflet coaptation. An additional 90° of rotation yielded a modified long-axis view perpendicular to leaflet coaptation. Biplane vena contracta width was obtained by calculating the average value from the long-axis and 2-chamber views.

Transthoracic echocardiography: Although the transesophageal probe remained inserted, a complete 2-dimensional echocardiographic and Doppler study was performed with a transthoracic transducer in the standard parasternal and apical views utilizing the same ultrasound machine. Qualitative grade of the severity of MR was based on a combination of factors, including the jet area, jet direction, proximal jet width, and left atrial size. Color gain was adjusted downward to the point at which background noise disappeared. Quantitative Doppler was performed as previously described.[19] The diameters of the aortic and mitral annulae were measured in the parasternal long-axis view at the base of the leaflets at the time of maximum opening with an additional measurement of the mitral annulus taken from the apical 4-chamber view. At least 3 measurements of each variable were averaged. The cross-sectional area of the aortic annulus was calculated by assuming a circular shape and applying the πr^2 formula. The mitral annulus area was measured as $\pi(D_{LAX}/2)(D_{AP}/2)$, assuming the elliptical orifice where D_{LAX} is the mitral annulus diameter in the long-axis view and D_{AP} is in the apical 4-chamber view. The time–velocity integral of the MR jet was measured by continuous-wave Doppler, which was guided by color flow mapping. The stroke volumes of the mitral and aortic valves were obtained by multiplication of the respective cross-sectional areas and time–velocity integrals. The difference of the mitral and aortic stroke volumes determined the regurgitant volume. The regurgitant fraction was calculated by dividing the regurgitant volume by the mitral stroke volume. The effective orifice area was determined by dividing the regurgitant volume by the regurgitant time–velocity integral.[20]

Vena contracta width: Studies were recorded on videotape with selected cineloops digitally transferred to a Macintosh IIci computer for subsequent analysis. The vena contracta was considered to be the narrowest region

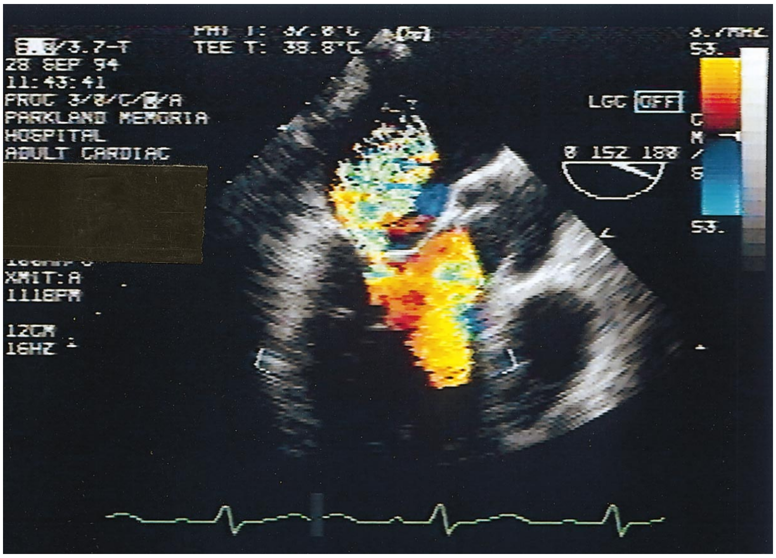

FIGURE 2. Measurement of vena contracta width (*arrow*) in the long-axis view during TEE.

of the jet as it emerged through the coaptation of the leaflets. Vena contracta width was measured in each view for ≥3 cardiac cycles. The largest diameter of the vena contracta during any portion of systole was taken. For eccentric jets, vena contracta width was always measured perpendicular to the long axis of the jet. Multiplane TEE images were analyzed separately by 2 experienced observers blinded to the clinical data.

Statistical analysis: Data are presented as mean ± 1 SD. Linear regression analysis was used to compare continuous variables. The qualitative grading of MR severity was compared with regurgitant volume, regurgitant fraction, and effective regurgitant orifice area by the analysis of variance method. Interobserver agreement was assessed by linear regression with Bland-Altman analysis.

RESULTS

Transthoracic echocardiography: MR jets were eccentric in 19 patients and central in 16 patients. The mean mitral time–velocity integral in 28 of the 35 patients was 130 ± 28 cm (range 76 to 170). The time–velocity integral could not be obtained in 8 patients due to technical difficulty. The mean regurgitant volume was 74 ± 54 ml (range 6 to 189). The mean regurgitant fraction was 0.53 ± 0.20 (range 0.08 to 0.82). The mean effective orifice area in the 28 patients for whom the time–velocity integral was obtained was 0.69 ± 0.45 cm^2 (range 0.04 to 1.69).

Multiplane transesophageal echocardiography: The vena contracta width was identified in 35 of the 36 patients (97%) in the long-axis view (Figure 2) compared with visualization in 32 patients (89%) using the 4-chamber view and in 31 patients (86%) using the modified 2-chamber view. The mean vena contracta width (centimeters) was 0.48 ± 0.25 in the 4-chamber view, 0.57 ± 0.32 in the modified 2-chamber view, 0.5 ± 0.27 in the 90° longitudinal view, and 0.50 ± 0.27 in the long-axis view.

Comparison of vena contracta width and mitral regurgitation severity: Table I shows the correlation coefficients and SEE for vena contracta width in various TEE views compared with quantitative Doppler assessment of MR severity. The best correlation was found in the long-axis view and is shown in Figure 3. The long-axis vena contracta width correlated well with regurgitant volume ($R^2 = 0.81$) and regurgitant orifice area ($R^2 = 0.81$). All patients with a vena contracta width ≥0.5 cm had a regurgitant volume >60 ml and an effective regurgitant orifice area ≥0.4 cm^2 (Figure 3). Conversely, all patients with a vena contracta width ≤0.3 cm^2 had a regurgitant volume <45 ml or an effective orifice area ≤0.35 cm^2. Patients with a vena contracta width between 0.3 and 0.5 cm^2 had a wide range of regurgitant volumes and regurgitant orifice areas. The relation between vena contracta width and quantitative Doppler measurements was similar for eccentric jets and central jets.

Interobserver variability: Vena contracta width was measured in all views in 21 randomly selected patients by 2 independent observers. Analysis of interobserver variability revealed excellent agreement ($R^2 = 0.96$) with a limited agreement of 0.06 cm.

DISCUSSION

Previous studies have reported that vena contracta width may be a useful method to assess the severity of MR. The present study is the first to compare simultaneous measurements of vena contracta width by multiplane TEE with quantitative Doppler measurements of regurgitant volume and effective regurgitant orifice area. Previous investigators have measured vena contracta width and proximal MR jet size by transthoracic echocardiography and reported larger discriminative values to identify severe MR when compared with the present study.[11–13] Studies by Hall et al[11] and Fehske et al,[12] using transthoracic echocardiography, have reported that vena contracta widths of 0.5 and 0.65 cm, respectively, have been associated with regurgitant volumes ≥60 ml. Differences in these values may be explained by differences in imaging planes with vena contracta width determined from the parasternal long-axis view in the former study and the apical long-axis view in the latter study. There is improved accuracy with axial resolution in the parasternal long-axis view compared with lateral resolution in the apical views. In the present study, a vena contracta width value of 0.5 cm identified the presence of severe MR by quantitative Doppler measurements.

The correlation of the biplane vena contracta width with regurgitant volume and effective regurgitant orifice area was not as good as the correlation that was observed with the long-axis vena contracta width

TABLE I Correlation of Biplane Vena Contracta Width With Regurgitant Volume and Effective Regurgitant Orifice Area

	Regurgitant Volume		Regurgitant Orifice Area	
Vena Contracta Width	R^2	SEE	R^2	SEE
Long-axis view	0.81	0.12	0.81	0.12
4-chamber view (0°)	0.55	0.17	0.44	0.18
2-chamber view	0.29	0.27	0.12	0.31
Longitudinal view (90°)	0.71	0.15	0.58	0.19
Biplane view	0.62	0.17	0.46	0.17

alone (Table I). A possible explanation is that, in most situations, MR worsens in the anteroposterior direction of the mitral valve orifice, which is directly aligned to the long-axis plane. However, the 2-chamber view is roughly parallel to the mitral valve orifice and could lead to overestimation of MR severity by vena contracta width (Figure 1).

Comparison with other methods: Although TEE measurements of proximal jet width and vena contracta width have been previously reported to correlate with angiographic regurgitant volumes,[14,15] the present study revealed excellent correlation with quantitative Doppler estimates of MR severity. Therefore, this study further validates the measurement of vena contracta width for assessing MR severity and provides a feasible alternative to Doppler color flow mapping, proximal flow convergence, and angiographic methods. Although Doppler color flow mapping of MR jets has been reported to correlate with angiographic grades of MR,[1,2] there has been limited correlation with regurgitant volume and regurgitant fraction. Furthermore, there is significant variability in color flow jet area measurement among observers and from day to day.[22,23] Hemodynamics and technical factors such as transducer frequency, gain setting, and pulse repetition frequency can result in variability of the Doppler color flow area.[3,4] Similarly, the proximal flow convergence method for assessing MR severity has technical limitations.[6,7] In addition to overestimation of the effective regurgitant orifice area in patients with mitral valve prolapse, the proximal flow convergence method is highly dependent on measurement of the radius from the orifice, which may be difficult to define. This technique requires the assumption of hemispheric flow fields and calculation of the maximum flow rate, which do not account for dynamic changes in the mitral orifice during systole. Unlike vena contracta width measurement, the assessment of MR severity by proximal flow convergence as well as by other methods, such as momentum analysis[23] or integrated Doppler backscatter,[24] requires time consuming analysis and are not readily available to most echocardiography labs.

Study limitations: In this study, quantitative Doppler measurements were used as the reference for comparison. This technique is limited by the potential error in measuring the diameter of the mitral and aortic annulae. However, the quantitative Doppler method has been previously validated in comparison with angiographic and scintigraphic stroke volumes.[19] and has provided reference measurements for MR severity in comparison with vena contracta width in a previous study with excellent correlation.[11] Angiography was not performed because it is a poor reference standard for assessing valvular regurgitation.[25]

During systole, dynamic changes in the mitral valve orifice have been previously documented.[26] Furthermore, changes in the orifice size influence the MR jet, and likewise the vena contracta width.[9] However, in the present study, cardiac translation prevented us from consistently tracking the vena contracta throughout all systolic frames. Had we been able to average vena contracta width throughout systole, the results may have been better. Although this method does not address multiple regurgitant orifices or an irregular orifice that is best visualized in the short-axis view, correlation with regurgitant volume was best observed in the long-axis view. The long-axis view is perpendicular to the mitral valve coaptation plane (Figure 1) and thus is oriented to better detect anteroposterior separation of the cusps with progressive MR.

The present study utilized a 2-dimensional tech-

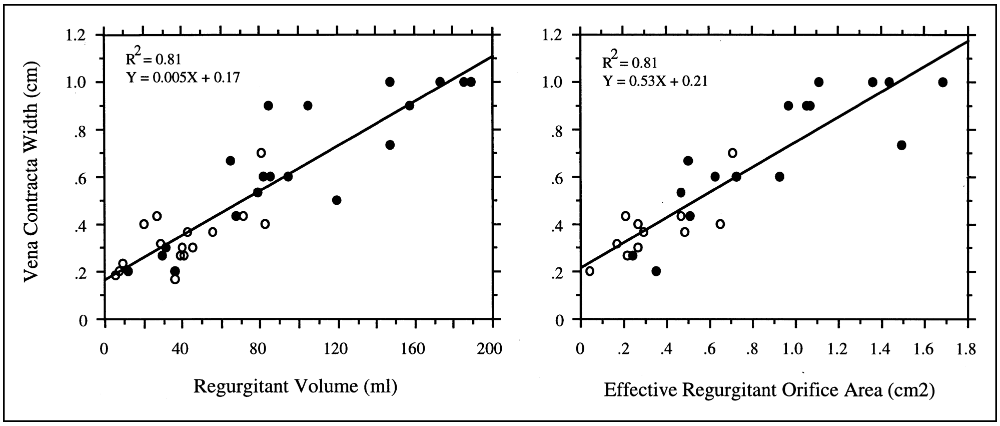

FIGURE 3. ***Left panel:*** **comparison of long-axis vena contracta width and MR regurgitant volume by quantitative Doppler.** ***Right panel:*** **comparison of long-axis vena contracta width and effective regurgitant orifice area.** ***Black circles,*** **values for patients with eccentric MR jets.**

nique to assess MR flow that is 3 dimensional. Future studies could overcome this limitation by 3-dimensional reconstruction of the vena contracta with multiplane TEE.

Clinical implications: As demonstrated previously, this study provides further support that measurement of vena contracta width is feasible in 97% of patients with MR. Additionally, this method is applicable to patients with atrial fibrillation as well as eccentric MR jets. There is significant potential to use vena contracta width in the perioperative assessment of patients who undergo mitral valve repair.[27] More importantly, this study indicates that a vena contracta width $\geq$0.5 cm is associated with a regurgitant volume $>$60 ml and an effective orifice area $\geq$0.4 cm^2 that are consistent with severe MR and thus may warrant surgical intervention. This clinical application is of great potential benefit because the timing of surgical intervention in patients with MR is critical to long-term outcome.[28–30] Patients with a vena contracta width $\leq$0.3 cm^2 have quantitative Doppler measures consistent with mild MR. Patients with an intermediate vena contracta width (0.4 cm) may have a wide range of MR severity and should undergo a more extensive Doppler evaluation, including quantitative Doppler and proximal flow convergence analysis.

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