Circulation

(*Circulation*. 1997;95:636-642.)

Articles

Assessment of Mitral Regurgitation Severity by Doppler Color Flow Mapping of the Vena Contracta

Shelley A. Hall, MD; M. Elizabeth Brickner, MD;
DuWayne L. Willett, MD; Waleed N. Irani, MD; Imran Afridi, MD;
Paul A. Grayburn, MD

the Division of Cardiology, Department of Medicine, University of Texas Southwestern and Veterans Administration Medical Centers, Dallas.

Correspondence to Paul A. Grayburn, MD, FACC, Division of Cardiology, UT Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75235-9047. E-mail grayburn@ryburn.swmed.edu.

Abstract

Background Although Doppler color flow mapping is widely used to assess the severity of mitral regurgitation (MR), a simple, accurate, and quantitative marker of MR by color flow mapping remains elusive. We hypothesized that vena contracta width by color flow mapping would accurately predict the severity of MR.

Methods and Results We studied 80 patients with MR. Vena contracta width was measured in multiple views with zoom mode and nonstandard angulation to optimize its visualization. Flow volumes across the left ventricular outflow tract and mitral annulus were calculated by pulsed-Doppler technique to determine regurgitant volume. Effective regurgitant orifice area was calculated by dividing the regurgitant volume by the continuous-wave Doppler velocity-time integral of the MR jet. The cause of MR was ischemia in 24, dilated cardiomyopathy in 34, mitral valve prolapse in 12, endocarditis in 2, rheumatic disease in 2, mitral annular calcification in 1, and uncertain in 5. Regurgitant volumes ranged from 2 to 191 mL. Regurgitant orifice area ranged from 0.01 to 1.47 cm^2. Single-plane vena contracta width from the parasternal long-axis view correlated well with regurgitant volume (r=.85, SEE=20 mL) and regurgitant orifice area (r=.86, SEE=0.15 cm^2). Biplane vena contracta width from apical views correlated well with regurgitant volume (r=.85, SEE=19 mL) and regurgitant orifice area (r=.88, SEE=0.14 cm^2). A biplane vena contracta width ≥0.5 cm was always associated with a regurgitant volume >60 mL and a regurgitant orifice area >0.4 cm^2. A biplane vena contracta width ≤0.3 cm predicted a regurgitant volume <60 mL and a regurgitant orifice area <0.4 cm^2 in 24 of 29 patients. No other parameter, including jet area, left atrial size, pulmonary flow reversal, or semiquantitative MR grade, correlated significantly with regurgitant volume or regurgitant orifice area in a multivariate analysis.

Conclusions Our results demonstrate that careful color flow mapping of the vena contracta of the MR jet provides a simple quantitative assessment of MR that correlates well with quantitative Doppler techniques.

Key Words: echocardiography • regurgitation • mapping

Introduction

Top
Abstract
Introduction
Methods
Results
Discussion
References

Doppler color flow mapping is widely used in clinical practice to assess the severity of mitral regurgitation (MR), usually by the area of the jet projecting into the left atrium.[1 2 3 4] However, jet area is limited by a variety of hemodynamic and technical factors and may markedly underestimate the severity of MR in eccentric wall jets.[5 6 7 8] Regurgitant volume can be calculated by quantitative Doppler, flow-convergence, or jet momentum methods,[9 10 11 12 13 14 15] but these also have limitations. Quantitative Doppler is time-consuming and cannot distinguish the severity of MR from that of aortic regurgitation in patients with both lesions. The flow-convergence method is complicated by geometrical assumptions regarding the shape of the proximal flow-convergence zone as well as the difficulty of precisely measuring its radius.[12 13] Jet momentum works well in axisymmetric free jets but is cumbersome and may not work well in eccentric jets.[16 17] Thus, these methods are limited for practical assessment of MR in terms familiar to most clinicians: mild, moderate, or severe.

Regurgitant orifice area has been proposed as a marker of lesion severity in valvular regurgitation.[18 19] Although direct visualization of the mitral regurgitant orifice area by transthoracic echocardiography is difficult, it can be closely approximated by measurement of the width of the vena contracta, defined as the narrowest cross-sectional area of a jet.[20] In vitro studies suggest that vena contracta width is relatively independent of hemodynamic variables and instrument settings.[21] Studies in animal models have shown that vena contracta measurement by color flow mapping is simple and accurately reflects regurgitant flow.[22 23] Fehske et al,[24] using transthoracic color flow mapping, showed that vena contracta width predicts angiographic severity of MR in 78 patients and correlates well with catheterization-derived regurgitant volume in a small subset of 23 patients. Similar findings were also reported for transesophageal color flow mapping.[25] This study was performed to (1) assess the accuracy of vena contracta width in evaluating the severity of MR compared with quantitative Doppler measures of regurgitant volume and regurgitant orifice area and (2) compare vena contracta width with other more traditional echocardiographic markers of MR severity.

Methods

Top
Abstract
Introduction
Methods
Results
Discussion
References

Patient Population

This study was performed prospectively in 80 patients referred for transthoracic echocardiography at Parkland Memorial Hospital (n=55) or the Dallas VA Medical Center (n=35). Patients were included in the study if they had at least mild MR by two-dimensional Doppler color flow imaging and if none of the following exclusion criteria were present: (1) aortic regurgitation or stenosis, (2) significant mitral stenosis, (3) acute myocardial infarction, (4) rhythms other than normal sinus, or (5) a prosthetic valve. Of 90 patients initially enrolled, 10 (11%) were excluded because of technically difficult echocardiograms. Specific reasons for this included inability to measure the diameter of the mitral annulus or left ventricular outflow tract (n=5), failure to visualize the vena contracta (n=3), or inability to obtain a continuous-wave Doppler profile of the mitral regurgitant jet (n=2).

Echocardiography

All patients underwent a complete two-dimensional echocardiographic and Doppler study in the left lateral decubitus position from multiple windows. Studies were performed with either a Vingmed CFM 750 or a Hewlett-Packard 2500 and were recorded on 0.5-in VHS tape. Chamber dimensions and wall motion score indexes were measured by standard methods.[26] Qualitative grade of the severity of MR was obtained from the clinical echocardiography report and was based on a visual impression combining the variables of jet area, jet direction, proximal jet width, left atrial size, pulmonary venous flow, and mitral valve morphology.

Color flow imaging was performed from the parasternal long-axis, apical four-chamber, apical two-chamber, and apical long-axis views. We did not evaluate short-axis views because in our experience, it is very difficult to identify the vena contracta from the parasternal short-axis plane. Color gain was adjusted downward to the point at which background noise just disappeared. The narrowest sector angle that allowed visualization of the MR vena contracta was used to maximize color flow imaging frame rate. Nyquist velocity ranged from 39 to 70 cm/s, and the low-velocity cutoff ranged from 8 to 16 cm/s. Both instruments use a tissue priority algorithm. On the Hewlett-Packard instrument, we used a red-blue map without variance (map A), which displays the highest detectable velocities as yellow toward and light blue away from the transducer. Since the vena contracta is part of the high-velocity core of the jet, it usually appeared as a discrete yellow or light blue area with this map. A red-blue color map with variance was used on the Vingmed instrument, which displays the vena contracta in bright green.[24]

In each patient, transducer angulation out of the standard echocardiographic planes was used to optimize visualization of the area of proximal flow acceleration, the vena contracta, and the downstream expansion of the jet (Fig 1). For each echocardiographic window, zoom mode was used to optimize visualization and measurement of the vena contracta. Vena contracta width was measured in each view from the systolic frame showing the largest diameter of a clearly defined vena contracta. For each view, an average of three beats was taken. To account for the possibility of nonsymmetrical orifices, a biplane vena contracta width was calculated from the measurements made in two roughly orthogonal apical views (Fig 2). The jet direction was classified by use of the initial direction of the jet immediately behind the point of mitral leaflet coaptation. Thus, eccentric jets were in close contact with a mitral leaflet behind the regurgitant orifice, whereas central jets were initially directed into the center of the left atrium. To determine maximal regurgitant jet area in any view, the transducer was carefully panned to achieve the largest jet area. The outline of this jet was traced manually, and the area was calculated by use of software programming already incorporated into the equipment.

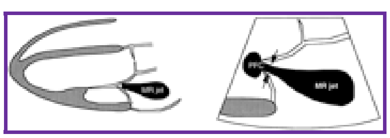


Figure 1. Left, Schematic of a parasternal long-axis view of a mitral regurgitation (MR) jet. Right, Zoom mode showing the vena contracta as the narrowest portion of the jet just downstream from the orifice (arrows). PFC indicates proximal flow convergence.

View larger version (15K):
[in this window]
[in a new window]

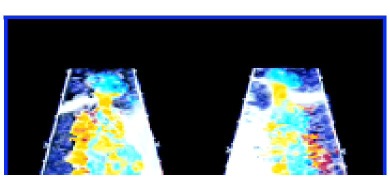
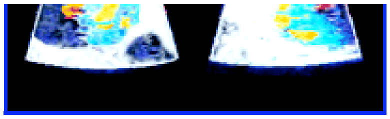


Figure 2. Color flow images from a patient in this study showing vena contracta width in the apical four-chamber (left) and two-chamber (right) views. A nonvarianced map is used in which the vena contracta appears as a bright yellow area just downstream from the orifice (arrows). Biplane vena contracta was calculated by



View larger version (49K):
[in this window]
[in a new window]

averaging the vena contracta widths in these two views.

Quantitative Doppler assessment was performed as previously described.[27,28] The diameter of the aortic annulus was measured in the parasternal long-axis view at the point of insertion of the aortic leaflets in systole. The diameter of the mitral annulus at the base of the leaflets at the time of maximal opening was measured in the parasternal long-axis and apical four-chamber views. The pulsed-wave Doppler signals at the mitral annulus and the aortic annulus were also taken from the apical window. The pulsed-wave Doppler data were measured on the brightest line (modal velocity). No angle corrections were used. At least three measurements of each variable were averaged. The cross-sectional area of the aortic annulus was calculated by the πr^2 formula, assuming a circular shape. Mitral annulus area was measured assuming an elliptical orifice as $\pi (D_{LAX}/2)(D_{AP}/2)$, where D_{LAX} is the mitral annulus diameter in the long-axis view and D_{AP} is in the apical four-chamber view. Continuous-wave Doppler, guided by color flow mapping, was used to measure the time-velocity integral of the mitral regurgitant jet.

The mitral and aortic stroke volumes were determined by multiplication of the cross-sectional area by the respective time-velocity integral. The regurgitant volume was calculated as the difference between the mitral and aortic stroke volumes. The regurgitant fraction was calculated as the regurgitant volume divided by the mitral stroke volume. The effective regurgitant orifice area was calculated as the regurgitant volume divided by the regurgitant time-velocity integral.[29]

Pulmonary vein flows were sampled by pulsed-Doppler technique. Images were obtained in the apical four-chamber view with transducer angulation to optimally visualize the pulmonary veins as they entered the left atrium. The pulsed-Doppler beam was then placed as far into the right and left pulmonary veins as possible, and flows were recorded. Pulmonary venous systolic flow reversal was considered an index of severe MR.[30]

Observer Agreement

In 20 randomly selected studies, two observers independently measured the vena contracta, and interobserver agreement was assessed by linear regression with Bland-Altman analysis.[31] These same studies were also reexamined by one observer at a separate time to determine intraobserver agreement.

Statistical Analysis

All values are reported as the mean±SD. Simple linear regression was used to compare vena contracta width and maximal jet area with regurgitant volume, regurgitant fraction, and effective regurgitant orifice area. These analyses were performed separately for eccentric jets and the entire group. ANOVA was used to compare the qualitative echocardiographic grading of MR with regurgitant volume, regurgitant fraction, and effective regurgitant orifice area. Stepwise multiple logistic regression was used to determine which variables were related to the severity of MR.

Results

Top
Abstract
Introduction
Methods

Patient Characteristics

The patients ranged in age from 23 to 78 years (mean, 56±13 years). There were 21 women and 59 men. The cause of MR was dilated cardiomyopathy in 34, ischemic heart disease in 24,

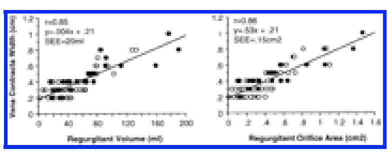
Discussion
References

mitral valve prolapse in 12, endocarditis in 2, rheumatic disease in 2, mitral annular calcification in 1, and undetermined in 5. By qualitative grading, 43 patients had mild MR, 21 moderate, and 16 severe. Six patients had a flail leaflet. Twenty-three patients had an eccentric jet, 19 of which were posteriorly directed, and the remaining 57 had a central jet. In 69 patients, a discrete zone of proximal flow convergence was visualized. Pulmonary vein flow was successfully measured in 69 patients and demonstrated flow reversal in 15. The Table summarizes the variables measured in this study.

View this table: **Table 1.** Echocardiographic Variables
[in this window]
[in a new window]

Relation Between Vena Contracta Width and Quantitative MR Severity

Vena contracta width could be identified and measured in the parasternal long-axis view in 75 patients (94%), the apical four-chamber view in 79 (99%), the apical two-chamber view in 65 (81%), and the apical long-axis view in 78 (98%). A single-plane vena contracta width measured in the parasternal long-axis view correlated well with regurgitant volume (*r*=.85, SEE=20 mL) and regurgitant orifice area (*r*=.86, SEE=0.15 cm^2) (Fig 3). The correlation was not changed when only eccentric jets (solid circles in Fig 3) were analyzed (*r*=.84 for regurgitant volume and *r*=.90 for regurgitant orifice area). A vena contracta width ≥0.5 cm in the parasternal long-axis view was always associated with a regurgitant volume >60 mL and a regurgitant orifice area >0.4 cm^2. A vena contracta width ≤0.3 cm predicted a regurgitant volume <60 mL and a regurgitant orifice area <0.4 cm^2 in 24 of 29 patients. Vena contracta width in the parasternal long-axis view also correlated with regurgitant fraction (*r*=.68, SEE=13%).



View larger version (16K):
[in this window]
[in a new window]

Figure 3. Linear regression plots showing good correlation between vena contracta width in the parasternal long-axis view and regurgitant volume (left) and regurgitant orifice area (right). Solid circles represent eccentric mitral regurgitation jets; open circles, central jets.

Fig 4 shows the relation between biplane vena contracta width and regurgitant volume and regurgitant orifice area for all the patients who had measurable vena contracta width in at least two apical views (78 of 80 study patients, 97%). Biplane vena contracta width correlated well with regurgitant volume (*r*=.85, SEE=19 mL) and regurgitant orifice area (*r*=.88, SEE=0.14 cm^2). Similar correlation coefficients were present when only eccentric jets (solid circles in Fig 4) were analyzed (*r*=.87 for regurgitant volume and *r*=.91 for regurgitant orifice area). A biplane vena contracta width ≥0.5 cm was always associated with a regurgitant volume >60 mL and a regurgitant orifice area >0.4 cm^2. A biplane vena contracta width ≤0.3 cm predicted a regurgitant volume <60 mL and a regurgitant orifice area <0.4 cm^2 in 24 of 29 patients. Although the relation between biplane vena contracta width and regurgitant fraction was also statistically significant, the correlation was only modest (*r*=.68, SEE=14%).

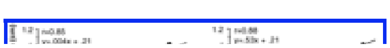
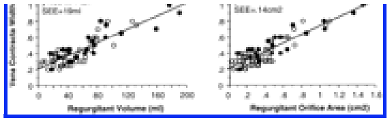


Figure 4. Linear regression plots showing good correlation between



biplane vena contracta width and regurgitant volume (left) and regurgitant orifice area (right). Solid circles represent eccentric mitral regurgitation jets; open circles, central jets.

View larger version (17K):
[in this window]
[in a new window]

Fig 5 shows the regurgitant orifice area calculated from biplane vena contracta widths assuming circular geometry compared with volumetric regurgitant orifice area by quantitative Doppler. Although a good correlation was present (r=.86, SEE=0.15 cm^2), vena contracta–determined regurgitant orifice area systematically underestimated the regurgitant orifice area by quantitative Doppler, as manifested by Bland-Altman analysis showing a mean difference between the two measurements of -0.23±0.18 cm^2.

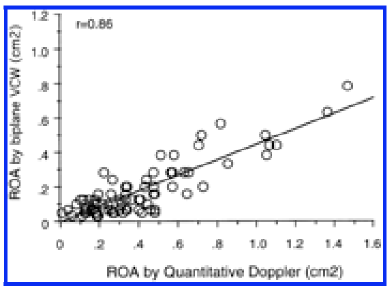


Figure 5. Linear regression plot showing regurgitant orifice area calculated from biplane apical vena contracta measurements (y axis) versus volumetric regurgitant orifice area by quantitative Doppler (x axis). Although a good correlation is present, regurgitant orifice area by vena contracta method systematically underestimates volumetric regurgitant orifice area.

View larger version (19K):
[in this window]
[in a new window]

Relation to Maximal Jet Area and Qualitative MR Severity

Fig 6 relates maximal jet area to regurgitant volume and regurgitant orifice area. Although statistically significant, the correlation is poor (r=.63 and r=.60 for regurgitant volume and regurgitant orifice area, respectively), with wide scatter in individual patients.

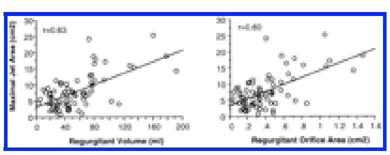
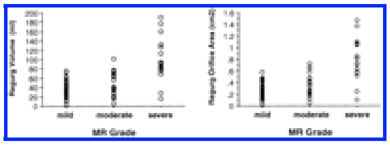


Figure 6. Linear regression plot showing only modest correlation between maximal jet area and regurgitant volume (left) and regurgitant orifice area (right).

View larger version (17K):
[in this window]
[in a new window]

Fig 7 relates qualitative grade of MR by Doppler color flow mapping to the quantitative measures of regurgitant volume and regurgitant orifice area. Although highly significant group differences between mild, moderate, and severe grades of MR are present for both regurgitant volume (F=30.9, P<.0001) and regurgitant orifice area (F=37.1, P<.0001), there is considerable scatter among individual patients.



View larger version (12K):
[in this window]
[in a new window]

Figure 7. Values of regurgitant volume (left) and regurgitant orifice area (right) for the various qualitative color flow grades of mitral regurgitation (MR) (*x* axis). Although the mean values were statistically significantly different among grades (see text), considerable overlap is present.

Variables Related to the Severity of MR

When stepwise multiple logistic regression was applied to the variables analyzed in this study, only the average vena contracta width was a strong predictor of mitral regurgitant volume (F=12.4, *P*=.001). Average vena contracta width (F=19.62, *P*=.0001) and to a much lesser extent, pathogenesis (F=2.42, *P*=.04) significantly predicted regurgitant orifice area by multiple logistic regression. Traditionally accepted markers of the severity of MR, such as pulmonary venous flow reversal, maximal jet area, and left atrial size, did not demonstrate significant correlation in the multivariate analysis.

Observer Agreement

Interobserver and intraobserver measurements of the average vena contracta width correlated closely (*r*=.97, SEE=0.04 cm and *r*=.94, SEE=0.07 cm, respectively). By Bland-Altman analysis, the mean difference in vena contracta measurements between two different observers was 0.02±0.08 cm. Similarly, the mean intraobserver difference in vena contracta measurements was within 0.01±0.09 cm.

Discussion

Top
Abstract
Introduction
Methods
Results
Discussion
References

Previous studies have shown the feasibility of vena contracta width as a marker of MR severity in humans. Fehske et al[24] studied 78 patients with vena contracta imaging by transthoracic color flow mapping. Vena contracta width correlated well with angiographic grading. In a subset of 23 patients with sinus rhythm, vena contracta width correlated with catheterization-derived regurgitant volume. Similar findings were reported by Grayburn et al,[25] who used multiplane transesophageal echocardiography in 80 patients, 35 of whom had regurgitant volume determined at catheterization. To the best of our knowledge, no clinical studies have assessed the relation of vena contracta width to effective regurgitant orifice area. This prospective study shows that careful measurement of the vena contracta of a mitral regurgitant jet by Doppler color flow mapping accurately predicts regurgitant volume and regurgitant orifice area. Compared with multiple traditional echocardiographic findings in patients with MR, vena contracta width emerged as the only independent predictor of MR severity by multivariate analysis.

Comparison With Other Methods

Jet area

Jet area is the most commonly used parameter for assessing the severity of MR by Doppler color flow mapping. Although jet area has been shown to correlate with angiographic grading of MR,[1 2 3 4] the latter is a poor gold standard that does not accurately reflect regurgitant volume. This study confirms the findings of previous studies showing a weak correlation between jet area and quantitative measures of the severity of MR, such as regurgitant volume and regurgitant fraction.[2 4] Technical factors that affect jet area include inappropriate gain settings, transducer carrier frequency, and pulse repetition frequency, among others.[5 6] Conversely, vena contracta width is not nearly as affected by gain settings or carrier frequencies as jet area.[5 6 21] Moreover, there is also significant interobserver variability in measuring jet area[6] ; this study demonstrates very low interobserver variability in measuring the vena contracta. Another major limitation of jet area has been its tendency to markedly underestimate MR severity in eccentric jets.[7 8] In this study, vena contracta width accurately predicted regurgitant volume and regurgitant orifice area in patients with eccentric jets (r=.85 and r=.86, respectively).

Proximal jet width

Because of the many limitations of jet area, several investigators have suggested that proximal jet width is a better marker of the severity of MR.[32,33] As shown in Fig 8, proximal jet width may differ significantly from vena contracta width. Careful transducer angulation, zoom mode, and high frame rates (>15 s^{-1}) are helpful to properly identify the vena contracta.

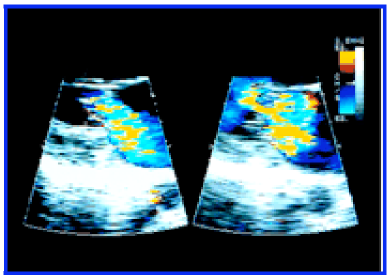


Figure 8. Color flow images using variance mode from a patient with a dilated cardiomyopathy and 2+ mitral regurgitation (MR) by angiography. Left, Standard parasternal long-axis view in which the proximal MR jet width appears large (1.1 cm). Right, With fine angulation of the transducer, the vena contracta is much narrower (0.4 cm). Regurgitant volume was 56 mL, with a regurgitant orifice area of 0.43 cm^2.

View larger version (52K):
[in this window]
[in a new window]

Flow-convergence method

Assessment of regurgitant flow rates by the flow-convergence method is based on sound physical principles.[9,10,11,12,13,14,15] However, in the clinical setting, this method has significant limitations.[13] It is subject to geometric complexities of the regurgitant orifice that require correction factors. For example, when the angle subtended by the surface of the hemispheric flow regions is not 180°, the flow equation must be modified. In addition, the hemispheric assumption does not hold true when proximity to the orifice causes the isovelocity surfaces to flatten out. This can be improved by lowering the color aliasing velocities (if the echocardiographic machine has such capability) to increase the measured radius. The importance of accurately depicting the radius cannot be overemphasized, because any errors in its measurement are squared in the flow equation. These pitfalls of the flow-convergence method, namely nonoptimal visualization of a flow-convergence region, are more common with severe regurgitation, mitral valve prolapse, and eccentric jets. Thus, whereas the flow-convergence method requires prolonged imaging time, technical expertise, and avoidance of the above-mentioned pitfalls, measurement of the vena contracta width is relatively simple and quick, and in vitro data suggest that it is independent of hemodynamics and orifice geometry.[21]

Momentum analysis

Thomas et al[16] have shown that jet momentum can be calculated from the velocities encoded in the color flow map. When combined with orifice velocity, momentum estimates orifice flow rates and effective orifice areas in in vitro models. However, this technique is fairly complicated and not readily accessible to the average clinician. In addition, this model has not been validated for pulsatile flow, exhibits wide velocity variation with turbulent jets, and may not work well with eccentric jets because of momentum transference to adjacent structures.[17]

Quantitative Doppler

In this study, quantitative Doppler was used as the reference standard for regurgitant volume and regurgitant orifice area. This method has been validated for patients with and without regurgitant valvular lesions, and its early pitfalls, mainly overestimation of the mitral annular time-velocity integral, have been identified and corrected.[27] However, it is fundamentally limited by its inability to distinguish individual valvular regurgitation severity in patients with combined aortic and mitral regurgitation. Therefore, we excluded patients with significant aortic regurgitation from this study. The measurement of vena contracta width offers some advantage over quantitative Doppler in that it is less technically demanding, provides more immediate assessment of MR severity, and may be less dependent on loading conditions than regurgitant volume.

Regurgitant orifice area

Recently, measurement of regurgitant orifice area by division of the regurgitant volume by the regurgitant time-velocity integral has been shown to be strongly predictive of the severity of MR.[29] However, direct visualization of the mitral regurgitant orifice area is difficult by transthoracic echocardiography. Vena contracta width provides a good approximation of regurgitant orifice area, as evidenced by this study.

Clinical Implications

Quantitative assessment of MR has proved to be problematic and yet necessary for decisions on medical management and surgical intervention. Since this assessment often needs to be made quickly (ie, intraoperatively), vena contracta width offers several advantages over previous techniques. First, it is simpler to use than proximal flow convergence, jet momentum, or quantitative Doppler. Second, it roughly approximates the regurgitant orifice area and appears to be relatively unaffected by hemodynamics, unlike jet area. Third, our study demonstrates that it is quantitative and predicts MR severity, with vena contracta widths >0.5 cm always associated with severe MR and those <0.3 cm usually associated with mild MR. Thus, only in patients with intermediate-size vena contracta widths, 0.3 to 0.5 cm, would additional methods such as quantitative Doppler be necessary to further clarify the valvular lesion severity.

Study Limitations

The pulsed-Doppler technique of calculating regurgitant volume and orifice area has technical limitations and is therefore an imperfect reference standard. It requires careful and precise measurement of the diameters of the left ventricular outflow tract and mitral annulus. Any error in these measurements will be squared in calculation of the cross-sectional area of the left ventricular outflow tract or multiplied in calculation of the cross-sectional area of mitral annulus. In addition, velocity measurements are angle dependent and can be difficult to obtain at the mitral annulus in patients with low cardiac outputs. To the best of our knowledge, there are no published studies validating the pulsed-Doppler technique against an independent reference standard. However, we have recently compared pulsed-Doppler measurements of regurgitant volume to simultaneous cardiac catheterization and found a good correlation (r=.84, SEE=23 mL) (unpublished data). Moreover, we have shown that MR vena contracta width by multiplane TEE correlates well with regurgitant volume calculated in the catheterization laboratory as the difference between angiographic and thermodilution stroke volumes.[25]

We studied only patients in normal sinus rhythm and thus cannot extrapolate these results to patients with atrial fibrillation, commonly seen in patients with MR. We did not analyze patients with both aortic and mitral regurgitation because of the limitations of quantitative Doppler. However, regurgitant orifice area and hence vena contracta width should not be affected by aortic regurgitation.

We did not measure vena contracta width in every frame throughout systole. Because of the motion of the mitral valve relative to the imaging plane, we did not find such an approach to be feasible. Instead, we measured the largest systolic vena contracta in each view. Given the dynamic nature of the mitral regurgitant orifice,[34 35 36] it is possible that the correlation would have been even better had we been able to measure mean systolic vena contracta width.

Finally, vena contracta width cannot be used to precisely calculate regurgitant orifice area by assuming either circular or elliptical geometry. The reason for this is schematically depicted in Fig 9, which shows a regurgitant orifice along the mitral coaptation plane. As can be seen, neither of the apical views is parallel to the leaflet coaptation plane. Therefore, multiplying any two biplane radii to calculate regurgitant orifice area results in underestimation of the volumetric regurgitant orifice area, as shown in this study (Fig 5). However, since worsening of MR tends to occur by anteroposterior separation of the cusps (except in unusual circumstances such as an abscess), vena contracta width should correlate linearly with severity of MR, as demonstrated in this study. In this study, a single parasternal long-axis view of the vena contracta correlated as well as orthogonal apical views with regurgitant volume and orifice area. This may be because the long-axis view is oriented anteroposterior to the mitral coaptation plane and because axial rather than lateral resolution was used to measure the vena contracta. Further studies would be helpful to determine whether the regurgitant orifice area could be reconstructed by sweeping the long-axis plane across the entire coaptation line from medial to lateral.

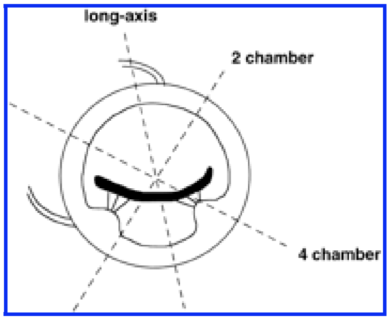


Figure 9. Schematic showing a short-axis view of left ventricle at papillary muscle level and mitral valve level superimposed. Mitral regurgitant orifice along coaptation line of mitral valve is shaded black. Lines intersecting regurgitant orifice represent image planes from apical four-chamber, two-chamber, and long-axis views. None of these views are aligned parallel to mitral coaptation. Therefore, calculation of mitral regurgitant orifice area from biplane apical views with the formula for area of an ellipse will underestimate true orifice area.

View larger version (15K):
[in this window]
[in a new window]

Conclusions

This study demonstrates that careful color flow mapping of the vena contracta of the MR jet provides a simple quantitative assessment of MR that correlates well with regurgitant volume and orifice, even in patients with eccentric jets.

Received June 24, 1996; revision received September 9, 1996; accepted September 12, 1996.

References

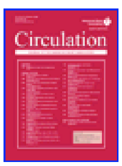
1. Helmcke F, Nanda N, Hsiung M, Soto B, Adey C, Goyal R, Gatewood R. Color Doppler assessment of mitral regurgitation with orthogonal planes. *Circulation*. 1987;75:175-183.[Abstract]
2. Spain M, Smith M, Grayburn P, Harlamert E, DeMaria A. Quantitative assessment of mitral regurgitation by Doppler color flow imaging: angiographic and hemodynamic correlations. *J Am Coll Cardiol*. 1989;13:585-590.[Medline]
3. Yoshida K, Yoshikawa J, Yamaura Y, Hozumi T, Akasaka T, Fukaya T. Assessment of mitral regurgitation by biplane transesophageal color Doppler flow mapping. *Circulation*. 1990;82:1121-1126.[Abstract]
4. Castello R, Lenzen P, Aguirre F, Labovitz A. Quantitation of mitral regurgitation by transesophageal echocardiography with Doppler color flow mapping: correlation with cardiac catheterization. *J Am Coll Cardiol*. 1992;19:1516-1521.[Medline]
5. Sahn D. Instrumentation and physical factors related to visualization of stenotic and regurgitant jets by Doppler color flow mapping. *J Am Coll Cardiol*. 1988;12:1354-1365.[Medline]
6. Hoit B, Jones M, Eidbo E, Elias W, Sahn D. Sources of variability for Doppler color flow mapping of regurgitant jets in an animal model of mitral regurgitation. *J Am Coll Cardiol*. 1989;13:1631-1636.[Medline]
7. Chen C, Thomas J, Anconina J, Harrigan P, Mueller L, Picard M, Levine R, Weyman A. Impact of

impinging wall jet on color Doppler quantification of mitral regurgitation. *Circulation*. 1991;84:712-720.[Abstract]

8. Enriquez-Sarano M, Tajik A, Bailey K, Seward J. Color flow imaging compared with quantitative Doppler assessment of severity of mitral regurgitation: influence of eccentricity of jet and mechanism of regurgitation. *J Am Coll Cardiol*. 1993;21:1211-1219.[Medline]
9. Bargiggia G, Tronconi L, Sahn D, Recusani F, Raisaro A, DeServi S, Valdes-Cruz L, Montemartini C. A new method for quantitation of mitral regurgitation based on color flow Doppler imaging of flow convergence proximal to regurgitant orifice. *Circulation*. 1991;84:1481-1489.[Abstract]
10. Rodriquez L, Thomas J, Monterroso V, Weyman A, Harrigan P, Mueller L, Levine R. Validation of the proximal flow convergence method: calculation of orifice area in patients with mitral stenosis. *Circulation*. 1993;88:1157-1165.[Abstract]
11. Schwammenthal E, Chen C, Benning F, Block M, Breithardt G, Levine R. Dynamics of mitral regurgitant flow and orifice area: physiologic application of the proximal flow convergence method: clinical data and experimental testing. *Circulation*. 1994;90:307-322.[Abstract]
12. Enriquez-Sarano M, Miller F Jr, Hayes S, Bailey K, Tajik A, Seward J. Effective mitral regurgitant orifice area: clinical use and pitfalls of the proximal isovelocity surface area method. *J Am Coll Cardiol*. 1995;25:703-709.[Medline]
13. Simpson I, Shiota T, Gharib M, Sahn D. Current status of flow convergence for clinical applications: is it a leaning tower of `PISA'? *J Am Coll Cardiol*. 1996;27:504-509.[Medline]
14. Chen C, Koschyk D, Brockhoff C, Heik S, Hamm C, Bleifeld W, Kupper W. Noninvasive estimation of regurgitant flow rate and volume in patients with mitral regurgitation by Doppler color mapping of accelerating flow field. *J Am Coll Cardiol*. 1993;21:374-383.[Medline]
15. Vandervoort P, Thoreau D, Rivera M, Levine R, Weyman A, Thomas J. Automated flow rate calculations based on digital analysis of flow convergence proximal to regurgitant orifices. *J Am Coll Cardiol*. 1993;22:535-541.[Medline]
16. Thomas J, Liu C, Flachskampf F, O'Shea J, Davidoff R, Weyman A. Quantification of jet flow by momentum analysis: an in vitro color Doppler flow study. *Circulation*. 1990;81:247-259.[Abstract]
17. Grayburn PA, Cigarroa CG, Willett DL, Brickner ME. Quantitative assessment of simulated regurgitant flow using direct digital acquisition of Doppler color flow images. *Echocardiography*. In press.
18. Reimold S, Ganz P, Bittl J, Thomas J, Thoreau D, Plappert T, Lee R. Effective aortic regurgitant orifice area: description of a method based on the conservation of mass. *J Am Coll Cardiol*. 1991;18:761-768.[Medline]
19. Vandervoort P, Rivera M, Mele D, Palacios I, Dinsmore R, Weyman A, Levine R, Thomas J. Application of color Doppler flow mapping to calculate effective regurgitant orifice area: an in vitro study and initial clinical observations. *Circulation*. 1993;88:1150-1156.[Abstract]
20. Yoganathan AP, Cape EG, Sung H-W, Williams FP, Jimoh A. Review of hydrodynamic principles for the cardiologist: applications to the study of blood flow and jets by imaging techniques. *J Am Coll Cardiol*. 1988;12:1344-1353.[Medline]
21. Baumgartner H, Schima H, Kuhn P. Value and limitations of proximal jet dimensions for the quantitation of valvular regurgitation: an in vitro study using Doppler flow imaging. *J Am Soc Echocardiogr*. 1991;4:57-66.[Medline]
22. Zhou X, Shiota T, Jones M, Yamada I, Teien D, Sahn DJ. Vena contracta imaging by Doppler color flow mapping predicts severity of mitral regurgitation: an animal study. *J Am Coll Cardiol*. 1996;27:284A. Abstract.
23. Ishii M, Jones M, Shiota T, Yamada I, Heinrich RS, Yoganathan AP, Sahn DJ. Quantifying aortic regurgitation by vena contracta imaging: a chronic animal model study. *J Am Coll Cardiol*. 1996;27:284A. Abstract.
24. Fehske W, Omran H, Manz M, Kohler J, Hagendorff A, Luderitz B. Color-coded Doppler imaging of the vena contracta as a basis for quantification of pure mitral regurgitation. *Am J Cardiol*. 1994;73:268-274.[Medline]
25. Grayburn PA, Fehske W, Omran H, Brickner ME, Luderitz B. Multiplane transesophageal echocardiographic assessment of mitral regurgitation by Doppler color flow mapping of the vena contracta. *Am J Cardiol*. 1994;74:912-917.[Medline]
26. Schiller N, Shah P, Crawford M, DeMaria A, Devereux R, Feigenbaum H, Gutgesell H, Reichek N, Sahn D, Schnittger I, Silverman N, Tajik J. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. *J Am Soc Echocardiogr*. 1989;2:358-367.[Medline]
27. Enriquez-Sarano M, Bailey K, Seward J, Tajik A, Krohn M, Mays J. Quantitative Doppler assessment of valvular regurgitation. *Circulation*. 1993;87:841-848.[Abstract]

28. Lewis J, Kuo L, Nelson J, Limacher M, Quinones M. Pulsed Doppler echo-cardiographic determination of stroke volume and cardiac output: clinical validation of two new methods using the apical window. *Circulation*. 1984;70:425-431.[Abstract]
29. Enriquez-Sarano M, Seward J, Bailey K, Tajik A. Effective regurgitant orifice area: a noninvasive Doppler development of an old hemodynamic concept. *J Am Coll Cardiol*. 1994;23:443-451.[Medline]
30. Klein A, Obarski T, Stewart W, Casale P, Pearce G, Husbands K, Cosgrove D, Salcedo E. Transesophageal Doppler echocardiography of pulmonary venous flow: a new marker of mitral regurgitation severity. *J Am Coll Cardiol*. 1991;18:518-526.[Medline]
31. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307-310.[Medline]
32. Mele D, Vandervoort P, Palacios I, Rivera J, Dinsmore R, Schwammenthal E, Marshall J, Weyman A, Levine R. Proximal jet size by Doppler color flow mapping predicts severity of MR. *Circulation*. 1995;91:746-754.[Abstract/Free Full Text]
33. Tribouilloy C, Shen W, Quere J, Rey J, Choquet D, Dufosse H, Lesbre J. Assessment of severity of mitral regurgitation by measuring regurgitant jet width at its origin with transesophageal Doppler color flow imaging. *Circulation*. 1992;85:1248-1253.[Abstract]
34. Yoran C, Yellin EL, Becker RM, Gabbay S, Frater RWM, Sonnenblick EH. Dynamic aspects of acute mitral regurgitation: effects of ventricular volume, pressure, and contractility on the effective regurgitant orifice area. *Circulation*. 1979;60:170-176.[Abstract]
35. Shiota T, Jones M, Teien DE, Yamada I, Passafini A, Ge S, Sahn DJ. Dynamic change in mitral regurgitant orifice area: comparison of color Doppler echocardiographic and electromagnetic flowmeter-based methods in a chronic animal model. *J Am Coll Cardiol*. 1995;26:528-536.[Medline]
36. Schwammenthal E, Chen C, Benning F, Block M, Breithart G, Levine RA. Dynamics of mitral regurgitant flow and orifice area: physiologic application of the proximal flow convergence method: clinical data and experimental testing. *Circulation*. 1994;90:307-322.[Abstract]

This article has been cited by other articles:



Circulation HOME

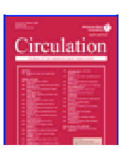
M. S. Turner, R. A. Bleasdale, D. Vinereanu, C. E. Mumford, V. Paul, A. G. Fraser, and M. P. Frenneaux
Electrical and Mechanical Components of Dyssynchrony in Heart Failure Patients With Normal QRS Duration and Left Bundle-Branch Block: Impact of Left and Biventricular Pacing
Circulation, June 1, 2004; 109(21): 2544 - 2549.
[Abstract] [Full Text] [PDF]

Heart HOME

J. D Thomas
DOPPLER ECHOCARDIOGRAPHIC ASSESSMENT OF VALVAR REGURGITATION
Heart, December 1, 2002; 88(6): 651 - 657.
[Full Text] [PDF]

Heart HOME

T Irvine, X K Li, D J Sahn, and A Kenny
Assessment of mitral regurgitation
Heart, November 1, 2002; 88(90004): iv11 - 19.
[Full Text] [PDF]



Circulation HOME

T. Buck, R. A. Mucci, J. L. Guerrero, G. Holmvang, M. D. Handschumacher, and R. A. Levine
The Power-Velocity Integral at the Vena Contracta : A New Method

for Direct Quantification of Regurgitant Volume Flow
Circulation, August 29, 2000; 102(9): 1053 - 1061.
[Abstract] [Full Text]

Circulation HOME
C. M. Tribouilloy, M. Enriquez-Sarano, K. R. Bailey, J. B. Seward, and A. J. Tajik
Assessment of Severity of Aortic Regurgitation Using the Width of the Vena Contracta : A Clinical Color Doppler Imaging Study
Circulation, August 1, 2000; 102(5): 558 - 564.
[Abstract] [Full Text] [PDF]

Circulation HOME
R. Shandas, J. Kwon, and L. Valdes-Cruz
A Method for Determining the Reference Effective Flow Areas for Mechanical Heart Valve Prostheses : In Vitro Validation Studies
Circulation, April 25, 2000; 101(16): 1953 - 1959.
[Abstract] [Full Text] [PDF]

Circulation HOME
Y. Mori, T. Shiota, M. Jones, S. Wanitkun, T. Irvine, X. Li, A. Delabays, N. G. Pandian, and D. J. Sahn
Three-Dimensional Reconstruction of the Color Doppler–Imaged Vena Contracta for Quantifying Aortic Regurgitation : Studies in a Chronic Animal Model
Circulation, March 30, 1999; 99(12): 1611 - 1617.
[Abstract] [Full Text] [PDF]

Circulation HOME
J. D. Thomas
How Leaky Is That Mitral Valve?: Simplified Doppler Methods to Measure Regurgitant Orifice Area
Circulation, February 4, 1997; 95(3): 548 - 550.
[Full Text]

Circulation HOME
Y. Otsuji, M. D. Handschumacher, E. Schwammenthal, L. Jiang, J.-K. Song, J. L. Guerrero, G. J. Vlahakes, and R. A. Levine
Insights From Three-Dimensional Echocardiography Into the Mechanism of Functional Mitral Regurgitation : Direct In Vivo Demonstration of Altered Leaflet Tethering Geometry
Circulation, September 16, 1997; 96(6): 1999 - 2008.
[Abstract] [Full Text]

Circulation HOME
E. Schwammenthal, S. Nakatani, S. He, J. Hopmeyer, A. Sagie, A. E. Weyman, H. M. Lever, A. P. Yoganathan, J. D. Thomas, and R. A. Levine
Mechanism of Mitral Regurgitation in Hypertrophic Cardiomyopathy : Mismatch of Posterior to Anterior Leaflet Length and Mobility
Circulation, September 1, 1998; 98(9): 856 - 865.
[Abstract] [Full Text] [PDF]

This Article

- **Abstract** FREE
- **Alert me when this article is cited**
- **Alert me if a correction is posted**
- **Citation Map**

Services