New Index for Grading the Severity of Aortic Regurgitation Based on the Cross-Sectional Area of Vena Contracta Measured by Color Doppler Flow Mapping

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This study was designed to examine whether the cross-sectional area of vena contracta measured by color Doppler flow mapping (CFM) could be used for assessing aortic regurgitation (AR) and developing an index for grading AR. The 75 study patients with AR were classified into quadrant grades according to New York Heart Association functional class, regurgitant fraction, left ventricular (LV) end-diastolic dimension and LV end-systolic dimension. Using CFM, the cross-sectional area of the vena contracta was measured and it could distinguish all grades without significant overlap. An area of less than 0.10 cm² corresponded to Grade 1, 0.10–0.19 cm² corresponded to Grade 2, 0.20–0.29 cm² corresponded to Grade 3 and an area of more than 0.30 cm² corresponded to Grade 4. An area of vena contracta of more than 0.30 cm² identified high-scoring AR (Grade 4) in 11 of 11 (sensitivity 100%) and correctly predicted the absence of high-scoring AR in 60 of 64 (specificity 94%). Conversely, there was considerable overlap between the jet distances with the clinical grades. The cross-sectional area of the vena contracta measured by CFM can provide a simple quantitative assessment of AR that correlates well with the clinical grade of AR. (Circ J 2003; 67: 243–247)

Key Words: Aortic regurgitation; Doppler echocardiography; Vena contracta

Because aortic regurgitation (AR) is the major disease that causes chronic heart failure and its quantification is important. Many attempts have been made to assess the severity of AR using ultrasound techniques, including pulsed-wave Doppler,1–10 continuous-wave Doppler11 and color Doppler flow mapping (CFM).12–14 As a semiquantitative grading, the measurement of the distance of the AR jet on the CFM image is commonly used in clinical setting12–14 but there is often a significant discrepancy between the clinical severity of AR and the jet distance. The discrepancy may be related to the particular cases that represent small volume, but have long and narrow jets. Although AR volume can be measured quantitatively by the combined use of pulsed Doppler and 2-dimensional (D) echocardiography, this method cannot be applied in patients with multiple left-sided valvular regurgitation.4,20

Recently, measuring the size of the vena contracta from the measurement of the proximal width of AR jet has been reported as a promising method for quantitative assessment of AR.16–18 We have also reported that the cross-sectional area of the vena contracta measured by CFM correlated well with the effective regurgitant orifice area calculated by quantitative Doppler.19 However, no data exist regarding the simple classification of the size of vena contracta in relation to the clinical grade of AR. Furthermore, there are no data for comparing the jet distance method with the vena contracta method in clinical practice. We propose a new index for AR based on the cross-sectional area of the vena contracta measured by conventional CFM and designed the present study to examine its utility and limitations in the assessment of AR.

Methods

The study population consisted of 89 prospectively evaluated patients with chronic AR (mean age 71±13 years, range 59–87 years). The major reason for referral to the echocardiographic laboratory was evaluation of diastolic heart murmurs, cardiomegaly detected by chest X-ray or ECG abnormalities with left ventricular (LV) hypertrophy. The diagnosis of AR was obtained with CFM, spectral pulsed and continuous-wave Doppler echocardiography. No patients had significant mitral regurgitation as diagnosed by pulsed Doppler as holosystolic intensive regurgitant signals or depicted by CFM as remarkable signals of proximal flow convergence. The patients with systolic aortic-LV pressure gradients of more than 20 mmHg assessed by transaortic flow velocity were excluded. None of the patients had a prosthetic valve. The etiologies of AR were sclerotic aortic valve (77 patients) and degenerative aortic valve, probably because of hyperlipidemia (12 patients). All patients had sinus rhythm with heart rate of 46–72 beats/min. Patients were in New York Heart Association (NYHA) functional class I (55 patients), II (28 patients), III (3 patients) and IV (3 patients) at the time of the study; 42 had been treated previously for more than 3 months with angiotensin-converting enzyme inhibitors (ACEI), 26 with calcium channel blockers, 7 with combined use of calcium channel blockers and diuretics, and 4 with combined ACEI and diuretics. At the ultrasound examination, brachial arte-
Table 1 Scores for Grading Aortic Regurgitation

<table>
<thead>
<tr>
<th>SCORE</th>
<th>NYHA</th>
<th>RF (%)</th>
<th>LVDd (mm)</th>
<th>LVDs (mm)</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>I</td>
<td>&lt;20</td>
<td>&lt;45</td>
<td>&lt;30</td>
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<tr>
<td>2</td>
<td>II</td>
<td>20–39</td>
<td>45–54</td>
<td>30–39</td>
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<tr>
<td>3</td>
<td>III</td>
<td>40–59</td>
<td>55–59</td>
<td>40–49</td>
</tr>
<tr>
<td>4</td>
<td>IV</td>
<td>≥60</td>
<td>≥60</td>
<td>≥50</td>
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NYHA, New York Heart Association functional class; RF, regurgitant fraction; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension.

Ultrasonic Examinations

We used a commercially available Doppler echocardiograph (Sequoia C256, Acuson and Siemens Company, Mountain View, CA, USA; EUB-6000, Hitachi Medical Corporation, Tokyo, Japan; SSD-5500, ALOKA Co, Ltd, Tokyo, Japan). Each patient was positioned in the left lateral decubitus position and breathed in a relaxed way during the imaging. Routine examinations, including M-mode measurements of LV diameter and LV ejection fraction, were performed before the Doppler flow measurements. The carrier frequency for spectral pulsed- and continuous-wave Doppler measurement was 2.5 or 3.5 MHz. The diameters of the flow tract were measured by 3.5 MHz transducer.

Regurgitant Fraction Estimated by Quantitative Doppler

To calculate AR volume, LV ejection flow volume and transmural LV inflow volume were calculated using the combination of pulsed Doppler and 2-D echocardiography.3,4,20 The flow volume of each flow tract was measured by multiplying the time–velocity integral of the flow velocity, and the estimated area of the flow tract at the sampling volume was posited. The LV ejection flow velocity was recorded at the LV outflow tract, and the transmural LV inflow velocity was recorded at the center of the mitral annulus. The diameter of the LV outflow tract was measured on the parasternal LV long-axis view in mid-systole. The diameter of the mitral annulus was measured on the apical 4-chamber view (diameter ‘a’) and the 2-chamber view (diameter ‘b’) at the base of the leaflets at the time of maximal valvular opening. The flow volume of the LV inflow was calculated as $FV_{in} = TVI_{in} \cdot \frac{1}{2} \cdot (a/2) \cdot (b/2)$, where $FV_{in}$ is LV inflow volume, $TVI_{in}$ is time velocity integral of LV inflow. LV outflow forward flow volume was calculated as $FV_{out} = TVI_{out} \cdot \frac{1}{2} \cdot (D/2)^2$, where $FV_{out}$ is the LV forward flow volume, $TVI_{out}$ is the time–velocity integral of the LV outflow, and $D$ is the diameter of the flow tract. Next, the AR volume was calculated as the difference between $FV_{out}$ and $FV_{in}$. The regurgitant fraction (RF) was calculated as:

$$RF\% = \frac{AR\ volume}{LV\ outflow\ volume \times 100}$$

All Doppler measurements were performed for 5 consecutive beats and the mean values were used for analysis.

Measurement of the Cross-Sectional Area of the Vena Contracta Using CFM and the Quadrant Grades

The set up of CFM for depicting the cross-sectional area of the vena contracta was standardized as: (1) carrier frequency ≥2.5 MHz, (2) standard colored velocity mapping mode, (3) maximal color gain without appearance of random noise, (4) Nyquist velocity within 50–80 cm/s, (5) maximum high-pass filter, (6) narrowest sector angle that provided adequate visualization of the vena contracta to maximize the frame rate, and (7) zoom mode in cases of small area for accurate tracing. Switching to CFM mode, we first depicted the parasternal long-axis color flow image of AR and in this image, it was observed that AR consisted of 3 components near the aortic valve: (a) an upper stream that converged toward the regurgitant orifice, (b) the vena contracta following the flow passing through the regurgitant orifice, and (c) the regurgitant jet spreading into the LV. Taking that structure of the AR jet near the aortic valve into consideration, we carefully adjusted the transducer position to depict the short-axis color flow images that corresponded to the vena contracta. Although it has been reported that the temporal variability of the vena contracta shows only a slight change in diastole, we measured its cross-sectional area with an on-line caliper during mid to late diastole to avoid the Doppler signals produced by valve closure.15 Measurements were performed for 5 consecutive beats and the mean values were used for analysis.

Based on the measurement of the cross-sectional area of the vena contracta, we designed a quadrant grading of AR: Trace: ≤0.09 cm², Mild: 0.10–0.19 cm², Moderate: 0.20–0.29 cm², and Severe: ≥0.30 cm².

Jet Distance Measured by CFM

As a comparison of the vena contracta method, we measured the maximum jet distance of AR from the aortic valve using the on-line caliper on the apical LV long-axis view.

Clinical Grade of AR Based on the Echocardiographic Measures and NYHA Functional Class

Based on the previously established echocardiographic measures of the severity of AR, including regurgitant fraction and LV dimensions, and the guidelines for the management of AR,1–3 we scored the severity of each parameter (Table 1). By integrating each score, we proposed quadrant grades: Grade 1: sum of score ≤6; Grade 2: sum of score is 7–9; Grade 3: sum of score is 10–12; Grade 4: sum of score is ≥13.

Fig 1. Representative recording of the cross-sectional image of the vena contracta. The area of the vena contracta in this patient was 0.22 cm².
AR Assessed by Doppler Mapping of Vena Contracta

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Intraobserver and Interobserver Variability

To examine the effect of intraobserver and interobserver variability on the measurement of the cross-sectional area of the vena contracta, 10 patients were randomly selected and measured by observer A at 2 separate times and also by another independent observer B. First, observer A performed the routine examination and the first measurement of vena contracta. Then, observer B measured the vena contracta of AR without knowledge of the result obtained by observer A. At the end of the routine examination, the second measurement of the vena contracta was performed by observer A.

Statistical Analysis

The data are expressed as mean±SD. Comparison of variables among the 4 groups was made using one-way ANOVA, followed by post hoc Scheffe’s multiple comparison test. Differences were considered to be statistically significant at p<0.05.

Results

Adequate images for analyzing the cross-sectional areas of the vena contracta were obtained in 75 patients (84% of the entry population). The cross-sectional area of the vena contracta ranged from 0.04 to 0.42 cm² (Fig 1), the regurgitant volume ranged from 4 to 104 ml/beat and the regurgitant fraction ranged from 10 to 69%.

The cross sectional area of the vena contracta in each clinical grade was clearly distinguished (Grade 1: 0.08±0.02 cm²; Grade 2: 0.15±0.04 cm²; Grade 3: 0.27±0.03 cm²; Grade 4: 0.36±0.04 cm²). The number of patients in each grade was 26 in Grade 1, 29 in Grade 2, 9 in Grade 3, and 11 in Grade 4. Consequently, an area of less than 0.10 cm², between 0.10 cm² and 0.19 cm², between 0.20 cm² and 0.29 cm², or more than 0.30 cm² corresponded to Grade 1, 2, 3, or 4, respectively (Fig 2). Furthermore, an area of vena contracta of 0.30 cm² or more identified high-scoring AR (Grade 4) with 100% sensitivity and correctly predicted the absence of severe AR in 60 of 64 (specificity 94%). Positive predictive value was 73% and negative predictive value was 100%.

The distance of the AR jet in each clinical grade was 4.92±1.11 cm in Grade 1, 6.66±1.52 cm in Grade 2, 8.28±0.76 cm in Grade 3, and 9.15±0.64 cm in Grade 4. There was considerable overlap between the jet distance and the clinical grade, so the jet distance method could not distinguish patients with and without severe AR (Fig 3). Although statistically significant differences were seen between Grade 1, 2 and 3, no significant difference existed between Grade 3 and 4 in the jet distance method.

Reproducibility

The vena contracta images of 10 patients were analyzed to examine the reproducibility. The mean absolute difference measured by 1 observer on 2 separate occasions (intraobserver variability) was 0.03±0.01 cm². Mean absolute difference measured by the 2 independent observers (interobserver variability) was 0.04±0.02 cm².

Discussion

We proposed a new index for grading AR based on the measurement of the cross-sectional area of the vena contracta and we present the 2 major findings from our investigation of the utility of this index. First, the cross-sectional area of the vena contracta can be measured in most patients with AR. Second, our quadrant grades based on the area of the vena contracta correlated well with other independent classifications of the severity of AR, and correctly predicted the AR severity.

Although the measurement of AR jet distance has been established as a simple Doppler echocardiographic method for assessing the clinical severity of AR, significant discrepancies exist between the clinical evaluation of AR and the jet distance. The discrepancy may be related to particular cases that have a small volume, but long and narrow jets and the errors may be caused by several other factors. The factors affecting jet distance are not only the regurgitant volume, but also the driving pressure between the aorta and left ventricle in diastole. Additionally, the jet distance of AR may be influenced by the interactions between the AR jet and the vortex caused by transmitral inflow. The ultrasonic penetration may also affect jet distance; indeed, long but narrow jets were often observed in thin patients. In contrast, the measurements of the vena contracta can overcome the problem because the size of the vena contracta is closely related to the size of the regurgitant orifice, which
is independent of pressure gradients. In previous studies, the width of the vena contracta was measured on the long-axis view probably because the theoretical Doppler principle is that the ultrasonic beam perpendicular to the flow cannot detect correctly the cross-sectional flow area. However, we have shown in our previous report that the cross-sectional area of the vena contracta can be measured by CFM and is closely related to the vena contracta calculated by the quantitative Doppler method.

The explanation for the ability of CFM to accurately measure the cross-sectional area of the vena contracta is unclear. A possible mechanism is that a very small angle between the transmitted ultrasonic beam and the regurgitant flow with high velocity may produce color flow signals on a ‘yes or no’ basis. Another possible mechanism is that the turbulent jet just beneath the vena contracta grazes the transmitted ultrasonic beam.

In fact, it has been reported that the cross-sectional area of the vena contracta can be measured even in the mitral regurgitation: Because the AR jet usually has a high velocity (>4 m/s), a sufficient Doppler shift frequency can be produced in such a small incident angle. Even considering these technical limitations, the measurement of the cross-sectional area of the vena contracta has more advantages compared with measuring the width of the vena contracta from the parasternal long-axis view. It has been reported that assessing AR severity by the width of the proximal jet may produce significant error in cases of an irregular orifice; but theoretically, the measurement of the cross-sectional area of the vena contracta can be applied even when there are slit-like, irregular or multiple lesions.

We proposed a new quadrant classification for the assessment of the severity of AR, based on the measurement of the cross-sectional area of the vena contracta. The major purpose of the present study was to develop simple and quantitative criteria for assessing AR severity using CFM. We found that the area of the vena contracta can distinguish clinical severity in most patients with AR. However, the size of the vena contracta may not correspond directly with the degree of heart failure, and there are various pathophysiological reasons in the cause of AR. Therefore, an assessment using multiple measures, including total LV function, may be required for clinical decision-making about AR. Although there are no absolute standards for the classification of the clinical severity of AR, the area of the vena contracta measured by CFM may be an additional good index for use in daily practice.

Study Limitations

The accuracy of the measurement of the cross-sectional area of the vena contracta largely depends on the imaging quality of the short-axis view at the level of the aortic valve. In fact, in 16% of the patients adequate short-axis images for analysis could not be obtained because of pulmonary emphysema, obesity, thoracic deformity or post radiation therapy. In such patients, the measurement method should be changed to that of the width of the vena contracta obtained from the long-axis view.

The vena contracta is characterized as the narrowest portion of the AR jet just beneath the orifice. Because the size of the cross-sectional area of the proximal jet changes abruptly in relation to the distance from the orifice, the success of the method depends on the most careful selection of the level of the vena contracta to be measured. Further studies are required to determine whether this method can be clinically applied in cases of the multiple regurgitant orifices.

Conclusions

The cross-sectional area of the vena contracta measured by CFM can provide a simple quantitative assessment of AR that correlates well with the clinical grade of AR.

References

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