Quantitation of Mitral Regurgitation by Transesophageal Echocardiography With Doppler Color Flow Mapping: Correlation With Cardiac Catheterization

RAMON CASTELLO, MD, PATRICIA LENZEN, RDCS, FRANK AGUIRRE, MD,
ARTHIUR J. LABOVITZ, MD, FACC

Saint Louis, Missouri

Eighty consecutive patients who underwent both left ventriculography and single-plane transesophageal echocardiography with Doppler color flow mapping were studied to compare the two techniques in the assessment of mitral regurgitation. Only the mosaic aspect of the regurgitant jet was included in the measurements. Values for intra- and interobserver variability for the maximal regurgitant area measurements were 10 ± 9% and 9 ± 8%, respectively.

The best correlation between angiography and Doppler color flow imaging was obtained with the maximal regurgitant area (r = 0.90). A maximal regurgitant area <6 cm² predicted mild mitral regurgitation with a sensitivity of 96%, specificity of 100% and a predictive accuracy of 98%, whereas a maximal regurgitant area >6 cm² predicted severe mitral regurgitation with a sensitivity of 91%, a specificity of 100% and a predictive accuracy of 98%. A strong, although inferior, correlation was found for the maximal regurgitant area/left atrial area ratio (r = 0.81). A ratio <20% predicted mild mitral regurgitation with 94% accuracy, whereas a ratio >35% predicted severe mitral regurgitation with 85% accuracy.

Thus, single-plane transesophageal echocardiography with Doppler color flow mapping is an exquisitely sensitive technique for the diagnosis of mitral regurgitation. Minimal degrees of mitral regurgitation can be detected in approximately 62% of patients in whom no mitral regurgitation is detected by angiography. The mosaic maximal regurgitant area is a simple and easily obtainable Doppler echocardiographic index that provides an accurate estimation of mitral regurgitation severity.

(J Am Coll Cardiol 1992;19:1516-21)

Methods

Study patients. The patient group was drawn from all patients who underwent both transesophageal echocardiography and cardiac catheterization at our institution between November 1988 and December 1990. Absence of any significant change in clinical status, systolic blood pressure or medications between the two procedures was required for inclusion in the study. The two studies were performed within 72 h in 71% of patients. A maximum of 7 days between studies was allowed, provided that the entry requirements were met. Systolic blood pressure at the time of the transesophageal echocardiographic study and left ventriculography was 134±22 and 130±23 mm Hg, respectively (p = NS).

There were 80 patients (33 men, 47 women) with a mean age of 59±15 years (range 14 to 84). Fifty patients had evidence of mitral regurgitation on the basis of left ventriculography in the evaluation of mitral regurgitation severity.
lation; the remaining patients had normal sinus rhythm. Informed written consent was obtained from all subjects.

Echocardiographic studies. All echocardiographic studies were performed by using a Doppler echocardiographic system (Hewlett-Packard 77020-A) with a 5-MHz transesophageal transducer. Topical anesthesia of the hypopharynx with Cetacaine or lidocaine and intravenous sedation with midazolam hydrochloride or meperidine were administered to all patients. All procedures were performed by two experienced cardiologists. The transmit power, color flow map, filters, packet sizes and sector arc were carefully maintained throughout all studies. Color flow gain settings were individually adjusted to the maximal possible level without appearance of artifacts. Mitral regurgitation was considered to be present when a high velocity or turbulent flow originating from the mitral valve was visualized in the left atrium during systole. By using different scanning planes, including four- and five-chamber views and the basal short-axis view, the maximal regurgitant area and the origin of the regurgitant jet were identified. All studies were recorded on 0.5 in. (1.27-cm) VHS tape for further analysis.

Angiographic studies. All patients included in the study underwent cardiac catheterization within 1 week of the echocardiographic study. Biplane left ventriculography was performed in a routine fashion, and the results were analyzed by one observer unaware of the results of the transesophageal echocardiographic study. Mitral regurgitation was graded from 0 to 4+ according to standard criteria (7). The left ventricular end-diastolic and end-systolic silhouettes were traced from the right anterior oblique ventriculogram to calculate ventricular volumes by the single-plane area-length method (8). Right heart catheterization was performed from the brachial or femoral vein with a Swan-Ganz catheter to measure pulmonary and wedge pressures, and cardiac output was calculated by the thermodilution technique. Regurgitant volumes were calculated in 21 patients with sinus rhythm and without significant aortic regurgitation by subtracting the thermodilution stroke volume from the angiographic stroke volume. The regurgitant fraction was obtained by dividing the regurgitant volume by the angiographic stroke volume and expressed as percent.

Doppler color flow analysis. Studies were analyzed by two independent observers unaware of the angiographic results. The video frame containing the maximal regurgitant jet area in which the origin of the abnormal regurgitant jet was also visualized was selected for analysis. All measurements were performed off-line with a commercially available echocardiographic analysis system (GT1 Freeland Medical). Only the mosaic aspect of the regurgitant flow areas was measured. Adjacent low velocity swirling flow was not included in the measurements (Fig. 1). The maximal regurgitant jet area, maximal width and length and the color jet width immediately behind the mitral valve were obtained by direct planimetry. The individual values of these four variables corresponding to three cardiac cycles were averaged. In patients with atrial fibrillation, five cardiac cycles were averaged. The left atrial area was traced in a similar fashion.

Figure 1. Color flow measurements. Left panel, Maximal regurgitant area (dashed line) corresponding to a patient with 3+ mitral regurgitation (maximal regurgitant area 6.03 cm²). The entire regurgitant jet is displayed as mosaic. Right panel, Maximal regurgitant area corresponding to a patient with 1+ mitral regurgitation. Note the difference between the mosaic area (short dashes) (maximal regurgitant area 1.2 cm²) and the total area (long dashes) including surrounding low flow (maximal regurgitant area 4.2 cm²)
Table 1. Inter- and Intraobserver Variation in Color Flow Measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Interobserver % Difference</th>
<th>Intraobserver % Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal regurgitant area</td>
<td>10 ± 9</td>
<td>9 ± 8</td>
</tr>
<tr>
<td>Maximal length</td>
<td>9 ± 7</td>
<td>8 ± 8</td>
</tr>
<tr>
<td>Maximal width</td>
<td>16 ± 12</td>
<td>11 ± 11</td>
</tr>
<tr>
<td>Size of left atrium</td>
<td>7 ± 12</td>
<td>7 ± 8</td>
</tr>
</tbody>
</table>

from the same frame in which the maximal regurgitant jet was obtained or from a different view containing the largest portion of the left atrium. When the entire left atrium could not be visualized, the unseen portions were approximated by visual interpolation.

Inter- and intraobserver differences. Color flow measurements in 20 randomly selected studies were performed by a second observer unaware of the previous measurements to determine interobserver variability. Both observers were allowed to review the studies in a blinded manner and to choose the largest regurgitant jet. To assess intraobserver variability, a second analysis was performed by the first observer 2 weeks later on the same 20 studies. Variability was calculated as the absolute difference between two observations divided by the mean and expressed as percent. Inter- and intraobserver variability was also evaluated by linear regression analysis with the least squares method.

Statistical analysis. All data are expressed as mean values ± SD. Correlation between echocardiographic and angiographic data was performed by the Pearson correlation analysis; p values <0.05 were considered significant.

Results

Technique and reproducibility. The maximal regurgitant jet area, length and width were adequately measured in all patients. The maximal color width at the origin of the regurgitant jet was difficult to obtain when only the mosaic pattern was included, and this variable could only be measured in 22 patients. Inter- and intraobserver differences for the color jet area, length and width are shown in Table 1. The correlations between measurements are shown in Figure 2.

The entire left atrial area could be visualized in only 7 (9%) of the 80 patients. Approximation by visual interpretation was obtained in all patients, and the inter- and intraobserver correlation coefficients for the assumed left atrial size were 0.97 and 0.98, respectively.

Regurgitant jet measurements and left ventriculography. Significant correlations were found between the degree of mitral regurgitation assessed by left ventriculography and the color flow regurgitant jet measurements, including the maximal regurgitant jet area, length and width. Although a strong correlation was also obtained with the ratio of maximal jet area to the approximated left atrial area (r = 0.81, p < 0.001), the absolute maximal regurgitant area was the echocardiographic variable that best correlated with the angiographic severity of mitral regurgitation (Fig. 3). The correlation coefficient was 0.90, whereas it was 0.79 for the maximal width and 0.83 for the maximal length. The maximal width at the origin of the jet was measured in only 22 patients and correlated poorly with angiography (r = 0.54, p < 0.03).

Of the 29 patients with no evidence of mitral regurgitation by angiography, 18 (62%) had mitral regurgitation by Doppler color flow mapping. All 18 of these patients showed a very small regurgitant color jet with a maximal area ranging from 0 to 1.74 cm² (mean 0.7 ± 0.62). The maximal regurgitant color flow area in the 19 patients with 1+ mitral regurgitation ranged from 0.92 to 3.2 cm² (mean 2.3 ± 0.6); in the group with 2+ mitral regurgitation it ranged from 3.5 to 5.6 cm² (mean 4.6 ± 0.7). The maximal regurgitant area in the 6 patients with 3+ mitral regurgitation ranged from 5 to 11.7 cm² (mean 7.6 ± 2.0), and that of the 16 patients with 4+ mitral regurgitation from 6 to 13.7 cm² (mean 9 ± 3). As expected, some overlap was observed.

Figure 2. Interobserver (left panel) and intraobserver (right panel) correlation for the maximal regurgitant color flow area.
Among the individual values in each grade of mitral regurgitation, however, some cut points provided good discrimination among groups. Forty-six of the 48 patients with 0 or 1+ mitral regurgitation had a maximal regurgitant area <3 cm² (sensitivity 96%, specificity 100%, predictive accuracy 98%). Twenty of the 22 patients with 3 to 4+ mitral regurgitation had a maximal regurgitant area >6 cm² (sensitivity 91%, specificity 100%, predictive accuracy 98%). The two patients with 3 to 4+ mitral regurgitation and a maximal regurgitant area <6 cm² had acute mitral regurgitation and a very eccentric regurgitant jet. In these patients interrogation of the left upper pulmonary vein with pulsed Doppler ultrasound revealed reversed systolic flow.

For the maximal regurgitant area/left atrial area ratio, the best cut points obtained were 20% and 35%, and a considerable overlap was noted (Fig. 4). Forty-six of the 48 patients with 0 to 1+ mitral regurgitation had a ratio <20% (sensitivity 96%, specificity 91%, predictive accuracy 94%).

Of the 22 patients with 3+ to 4+ mitral regurgitation, 14 had a ratio >35% (sensitivity 64%, specificity 93%, predictive accuracy 85%). We found the maximal regurgitant area/left atrial area ratio to be quite variable in the 3+ to 4+ mitral regurgitation group, with values ranging from 25% to 95%.

Relation of regurgitant jet area to jet direction, chronicity and hemodynamics. The majority of patients with 1+ to 2+ mitral regurgitation exhibited a centrally directed regurgitant jet; however, 16 of the 22 patients in the group with 3+ to 4+ mitral regurgitation showed an eccentric jet directed toward the anteromedial or posterolateral walls of the left atrium. Among patients with severe mitral regurgitation, there were no differences in the maximal regurgitant area between patients with chronic or acute mitral regurgitation (8.9 ± 3 vs. 8.4 ± 2.9 cm²) or a centrally directed or eccentric jet (9.2 ± 3 vs. 8 ± 2.8 cm²).

All echocardiographic color flow measurements were compared with hemodynamic variables. Significant but weak and scattered correlations were found between the maximal regurgitant area and left ventricular end-diastolic pressure (r = 0.29, p < 0.05) and regurgitant fraction (r = 0.45, p < 0.05). Patients with severe mitral regurgitation had a mean regurgitant fraction of 55 ± 17%, but considerable overlap was found in patients with mild or moderate mitral regurgitation.

Discussion

Quantitation of mitral regurgitation by Doppler color flow mapping. Initial color flow studies with transthoracic echocardiography showed that Doppler color flow measurements correlated fairly well with angiographic results in the diagnosis and assessment of mitral regurgitation severity. In the early studies, only the regurgitant jet length (the greatest distance reached by the regurgitant flow from the mitral valve orifice) was considered, resulting in significant overlap among the different mitral regurgitant grades (2). To overcome these limitations, Helmcke et al. (9) used the regurgitant jet area (maximum or average from three orthogonal planes) expressed as a percent of the left atrial area expressed as a percent of the left atrial area and obtained very close correlation with angiographic data, and minimal overlap was noted. In a subsequent study, Spain et al. (10) found the maximal regurgitant area obtained in any view to correlate best with angiographic values. These investigators stressed the value of this measurement for clinical purposes, because it is easy to obtain, reproducible and avoids the use of two measurements to quantitate mitral regurgitation.

These characteristics are of particular importance when using transesophageal echocardiography. Although the transesophageal technique offers the advantage of excellent image quality of the mitral valve and the left atrium, in most cases the entire left atrium cannot be visualized in a single view. To image the left atrium and the regurgitant jets entirely, it is necessary to use multiple views and slight variations of the standard planes at the time of the study.
compared epicardial with transesophageal echocardiography in the assessment of mitral regurgitation, and excellent correlation was found between the two techniques with regard to the maximal area and length of the regurgitant jets; however, correction for left atrial size could be obtained by transesophageal echocardiography in only 38% of patients. Thus, measurement of the maximal regurgitant area rather than its ratio to left atrial area is the rule in transesophageal studies (12-14). We were able to visualize the entire left atrium in only seven of our patients. In an attempt to utilize this echocardiographic index, visual assumptions of the unseen portions of the left atrial area were made during the off-line analysis. Although excellent correlations for the left atrial size measurements were noted between the two independent observers (r = 0.97), the maximal regurgitant area/left atrial area ratio in the present study did not provide the best correlation with angiographic grade, probably owing to the inaccuracy of the left atrial area measurements. Consistent with the results obtained by Spain et al. (10) in trans-thoracic studies and Yoshida et al. (13) in transesophageal studies, the maximal regurgitant area was the color flow measurement that best correlated with angiographic findings (r = 0.90).

Color flow analysis and determinants of the color regurgitant area. The Doppler color flow appearance of the regurgitant jet depends on many factors, including the algorithm employed to encode velocity information, color gain settings and transducer and pulse repetition frequency (15,16). In addition, anatomic factors, such as the regurgitant orifice size or the type of mitral regurgitation (that is, flail mitral valve or mitral anulus dilation), are known to modify the regurgitant jet area (17,18). To minimize potential sources of variability in the actual display of the regurgitant jets, all echocardiographic studies were performed with the same echocardiographic unit, and the color flow map, transmit power, filters, packet size and sector arc were carefully maintained throughout all studies. In addition, only the central core areas of the regurgitant jets exhibiting a mosaic pattern were included in the measurements. Some previous investigators (19,20) have measured the mosaic core of the regurgitant jet along with any bluish or reddish surrounding components, which resulted in a high interobserver variability for jet area. We have found that restricting the measurements to the mosaic component of the regurgitant jet results in a more accurate estimation of the area, thus minimizing inter- and intraobserver variability (21).

Yoshida et al. (13) used biplane transesophageal Doppler color flow mapping and obtained very similar results to ours in assessing mitral regurgitation, although in a smaller number of patients. In our study, a maximal regurgitant area <3 cm² predicted no or mild mitral regurgitation with a sensitivity of 96% and a specificity of 100%. A maximal regurgitant area >6 cm² predicted severe mitral regurgitation with a sensitivity of 91% and a specificity of 100%. Their cut points to identify mild, moderate and severe mitral regurgitation were 4 and 7 cm², respectively, and the predictive accuracy was very similar to ours (13).

Several factors may explain these minor differences. Twelve of the 22 patients with severe mitral regurgitation in our study had acute mitral regurgitation, which usually results in a smaller regurgitant jet area than that associated with chronic mitral regurgitation (22). In addition, 15 of the 22 patients had a flail mitral leaflet with an eccentric regurgitant jet. Previous experience from our (18) and other (23) laboratories has shown that patients with an eccentric jet exhibit a smaller regurgitant area than that of patients with a central regurgitant jet. Finally, our color flow analysis restricting the measurements to the mosaic area alone results in a smaller regurgitant jet area in some patients (21). Therefore, these cut points (3 and 6 cm²) should be useful in the quantitation of mitral regurgitation by transesophageal echocardiography, although some variation and overlap are expected.

Although we found a maximal regurgitant area >6 cm² to be very specific for severe mitral regurgitation, two patients with severe mitral regurgitation confirmed by cardiac catheterization exhibited a regurgitant area <6 cm². Both patients had acute mitral regurgitation with an extremely eccentric regurgitant jet. Biplane transesophageal echocardiography might be very useful in such patients; however, even with this technique, 2 of the 12 patients with severe mitral regurgitation in the series of Yoshida et al. (13) exhibited a regurgitant area <7 cm².

When using single-plane transesophageal echocardiography a meticulous search for the eccentric jet should be performed. In addition, interrogation of the pulmonary venous flow with pulsed Doppler ultrasound can be very useful. The two patients with severe mitral regurgitation and a maximal regurgitant area <6 cm² had reversed systolic pulmonary venous flow. Reversal of pulmonary venous flow during systole is a highly sensitive and specific sign of severe mitral regurgitation (24).

Color flow measurements and hemodynamics. Lack of strong correlation between the regurgitant color flow measurements and hemodynamic variables has been repeatedly described. Spain et al. (10) failed to find any significant correlation between the maximal regurgitant area and the regurgitant fraction or volume in patients with chronic mitral regurgitation. No improvement in these correlations was noted even when only patients with an ejection fraction >45% were considered. Similar results were obtained in our laboratory (18) when patients with a flail mitral leaflet and severe mitral regurgitation were evaluated. However, Helmcke et al. (9) were able to demonstrate good correlation between the maximal regurgitant area/left atrial area ratio and the angiographic regurgitant fraction (r = 0.78). In the present study with transesophageal echocardiography, only a weak but significant correlation between the maximal regurgitant area and left ventricular end-diastolic pressure and regurgitant fraction was observed (r = 0.29 and r = 0.45, respectively).
Similar discrepancies between the angiographic severity of mitral regurgitation and hemodynamic indexes of regurgitant volume have been reported (25). A number of assumptions are made when calculating regurgitant fraction, and the limitations of this technique have been well described (8).

Conclusions. Single-plane transesophageal echocardiography with Doppler color flow mapping is an extremely sensitive technique for the diagnosis of mitral regurgitation. It will detect some degree of regurgitation in approximately 62% of patients who have no regurgitation by left ventriculography.

The mosaic maximal regurgitant area is the echocardiographic variable that best correlates with angiographic findings in the assessment of mitral regurgitation severity \((r = 0.90)\). A maximal regurgitant area \(< 3 \text{ cm}^2\) predicts mild or severe mitral regurgitation, respectively, with a 98% accuracy on transesophageal studies. The maximal regurgitant area/left atrial area ratio has limited applicability, since it is not possible to visualize the entire left atrium in a substantial proportion of patients.

We express our gratitude to Lori Gallini Meeker and Kathryn Banker for excellent secretarial assistance.

 References