Transesophageal Doppler Echocardiography of Pulmonary Venous Flow: A New Marker of Mitral Regurgitation Severity

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Pulmonary venous flow varies with different cardiac conditions. Flow patterns in response to mitral regurgitation have not been well studied, but flows may vary enough to differentiate among different grades of regurgitation. Accordingly, pulmonary venous flow velocities were recorded in 50 consecutive patients referred for outpatient (n = 26) or intraoperative (mitral valve repair; n = 24) echocardiographic examination for mitral regurgitation. Recordings were made of right and left upper pulmonary veins with pulsed wave Doppler transesophageal echocardiography. Mitral regurgitation was graded from 1+ to 4+ by an independent observer using transesophageal color flow mapping. The results of cardiac catheterization performed 5 weeks earlier in 43 of the patients were also graded for mitral regurgitation by an independent observer.

Pulmonary venous flow patterns, the presence of reversed systolic flow and peak systolic and diastolic flow velocities were compared with the severity of mitral regurgitation indicated by each technique. Of the 28 patients with 4+ regurgitation, transesophageal color flow mapping, 26 (93%) had reversed systolic flow. The sensitivity of reversed systolic flow in detecting 4+ mitral regurgitation by transesophageal color flow mapping was 93% and the specificity was 100%. The sensitivity and specificity of reversed systolic flow in detecting 4+ mitral regurgitation by cardiac catheterization were 86% and 81%, respectively. Discordant flows were observed in 9 (24%) of 38 patients; the left vein usually showed blunted systolic flow and the right showed reversed systolic flow. In 22 intraoperative patients, there was "normalization" of pulmonary venous systolic flow after mitral valve repair in the postcardiopulmonary bypass study compared with the prebypass study after the mitral regurgitant leak was corrected.

Thus, this study demonstrates the effect of mitral regurgitation on pulmonary venous flow patterns and the use of reversed systolic flow in the pulmonary veins in identifying severe 4+ mitral regurgitation.

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Echocardiography with Doppler color flow mapping accurately assesses the severity of mitral regurgitation by spatially mapping the regurgitant jet into the left atrium (1,2). However, several technical and physiologic factors may limit this technique, including gain settings of the instrument, eccentric jets, the size of the regurgitant orifice, driving pressure and the compliance of the left ventricle and atrium (3-5). Therefore, improved techniques are needed to assess the severity of mitral regurgitation.

The systolic reflux of contrast dye into the pulmonary veins during left ventriculography is an angiographic sign of severe (4+) mitral regurgitation (6). Recently, transesophageal echocardiography has become available as a new acoustic window to the heart and provides an excellent visual image of the pulmonary veins as they enter the left atrium (7). Pulmonary venous flow can be easily assessed in most patients with pulsed wave Doppler echocardiography of the right and left upper pulmonary veins (8,9). Normal pulmonary venous flow is composed of a biphasic or triphasic forward flow during systole and diastole (Fig. 1) (10-13). Increases in the severity of mitral regurgitation may be associated with alterations in the normal pulmonary venous flow pattern on transthoracic echocardiography (12). Pulmonary venous flow patterns on transesophageal echocardiography have yet to be used to quantify the severity of mitral regurgitation. Therefore, the purpose of this study was to measure the effect of different grades of mitral regurgitation on pulmonary venous flow assessed with outpatient or intraoperative transesophageal echocardiography.

Methods

Study patients. The study group consisted of 50 consecutive patients (29 men and 21 women; mean age 60 ± 13 years, range 26 to 84) with clinically significant mitral
regurgitation who were referred for outpatient transesophageal echocardiography (n = 26) or had intraoperative transesophageal echocardiographic studies before and after surgical mitral valve repair (n = 24). Patients with significant native or prosthetic mitral stenosis (mitral valve area ≤1.5 cm²) were excluded from the study.

Echocardiographic examination. Complete two-dimensional, pulsed wave and Doppler color flow transthoracic and transesophageal echocardiograms were recorded with commercially available equipment (Hewlett-Packard, model 77020A; Acuson Computed Sonography, model 128). A 5-MHz phased-array monoplane transducer mounted on the tip of a gastroscope was used for the transesophageal study. A 2.25-MHz transducer was used for the transthoracic study.

Patient preparation. All outpatients received local anesthesia in the pharynx with lidocaine spray and intravenous antibiotic agents according to the guidelines of the American Heart Association (14). All were sedated with intravenous midazolam (0.5 to 1 mg) or meperidine (25 to 50 mg), or both, and the gastroscope was passed according to established techniques with the patient in the left lateral decubitus position (16).

All intraoperative patients were supine and the gastroscope was passed with the endotracheal tube in position. Transesophageal echocardiography was usually performed before median sternotomy, pericardiotomy and cardiopulmonary bypass (prebypass). The measurements were repeated after cardiopulmonary bypass (postbypass) after adequate blood pressure was restored (15,16).

Doppler color flow examination. Pulmonary venous flow was seen as an orange color on the flow map, representing flow toward the transducer entering the left atrium from the right upper and left upper pulmonary veins at the level of the basal short-axis view of the pulmonary veins (7). Pulsed wave Doppler echocardiography was performed by placing the sample volume into the pulmonary vein at approximately 1 to 2 cm beyond the orifice of the vein into the left atrium (Fig. 2) (18,19). The angle between the ultrasound sample volume and the pulmonary vein was minimized (17).

Echocardiographic measurements. Parasternal short-axis transthoracic images at the mid-ventricular level were used to derive the following M-mode measurements: left ventricular end-diastolic and end-systolic dimensions and fractional
shortening and left atrial size. The ejection fraction was derived according to the method of Quinones et al. (18). In five patients, the transthoracic echocardiogram was not adequate for measurements; therefore, the transesophageal transgastric short-axis images at the mid-ventricular level were used to derive fractional shortening and ejection fraction (19).

Doppler flow measurements. Valvular regurgitation by transesophageal Doppler color flow mapping was assessed by an independent observer (who was unaware of the pulmonary venous flow velocities) by visually mapping the length, height, width and area of the regurgitant jet by a method similar to that described by Helmeke et al. (20) for transthoracic echocardiography. The severity of mitral regurgitation was graded on a scale of 1+ to 4+ (mild = 1+, moderate = 2+, moderately severe = 3+ and severe = 4+) by visually comparing the dimensions of the jet to the size of the left atrium. The jet configuration, including jet direction (eccentric vs. central) and vortex formation or swirling, was also assessed.

Right and left pulmonary venous flow velocities were measured with use of a digitizing tablet (Dextra). Mean values were obtained by averaging at least three to six consecutive beats. Pulmonary venous flow velocities were divided into two distinct forward components: ventricular systolic and diastolic. Peak systolic and diastolic flow velocities were measured from baseline to the peak (21,22).

Pulmonary venous flows were categorized into one of three patterns: reversed systolic, blunted or normal. Reversed systolic flow was defined as retrograde flow that occupied the predominant portion of systole and was indicated by a tracing below the baseline. For quantitative purposes, reversed systolic flow was assigned a peak systolic velocity value of 0, indicating no forward flow during systole (8,9).

Blunted systolic flow was defined as a ratio of peak systolic to diastolic flow velocity between 0 and <1. Normal pulmonary venous flow was defined as a ratio of peak systolic/diastolic flow of =1. "Normalization" of pulmonary venous flow in the postbypass intraoperative study was defined as an increase in peak systolic velocity compared with the prebypass velocity or a peak systolic/diastolic flow ratio =1, or both.

Cardiac catheterization. Of the 50 patients, 43 (86%) had ventriculographic studies performed at a mean 5 ± 6 weeks (range 0 to 21) from the transesophageal echocardiographic study. The severity of mitral regurgitation was graded by an independent observer according to the method of Sellers et al. (23) as mild (1+), moderate (2+), moderately severe (3+) or severe (4+). The absolute height of the V wave from the pulmonary capillary wedge tracing during cardiac catheterization or the intraoperative study was also recorded.

Statistical analysis. Statistical significance of the difference between the mean Doppler pulmonary venous systolic and diastolic variables and the different grades of mitral regurgitation were evaluated by ANOVA (analysis of variance) techniques. The detection of severe (4+) mitral regurgitation by the presence of reversed systolic flow was assessed by sensitivity and specificity. Similarly, the detection of moderately severe (3+) mitral regurgitation by the presence of blunted systolic flow was assessed by sensitivity and specificity. These measures were compared with results of both transesophageal color flow mapping and cardiac catheterization. A comparison between the grading of mitral regurgitation by these two methods was assessed by the kappa statistic. Linear contrasts were used to evaluate differences between patients with 4+ mitral regurgitation and those with 2+ and 3+ mitral regurgitation. Bonferroni adjustments in alpha level were made to accommodate multiple comparisons. Unpaired t tests were used to evaluate differences in pulmonary venous flow characteristics for patients with and without reversed systolic flow. A p value <0.05 was considered statistically significant. The data for peak systolic and diastolic flow velocities are presented as mean values ± 1 SD.

Results

Clinical, hemodynamic and echocardiographic findings (Table 1). Patients with 4+ mitral regurgitation had a faster heart rate, a higher absolute V wave on the pulmonary capillary wedge pressure tracing and a larger left atrium compared with patients with 2+ and 3+ mitral regurgitation. The predominant cause of mitral regurgitation was degenerative mitral valve disease in 27 (54%) of the 50 patients; 11 (22%) had ischemic disease, 6 (12%) had rheumatic disease, 5 (10%) had prosthetic valve disease and 1 (1%) had endocarditis. The predominant pathologic finding in 16 (32%) of these 27 patients with degenerative disease was posterior chordal rupture; 4 patients (15%) had anterior chordal rupture. An eccentric mitral regurgitant jet (mainly anteromedial) was more common than a central jet in the study patients.

| Table 1. Clinical, Hemodynamic and Echocardiographic Characteristics of 50 Patients With Mitral Regurgitation |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | 2+              | 3+              | 4+              |
|                  | (n = 50)        | (n = 27)        | (n = 27)        |
| Age (yrs)       | 60 ± 13         | 62 ± 11         | 62 ± 15         | 58 ± 13         |
| Male/female     | 29/21           | 5/5             | 6/6             | 6/10            |
| New York Heart Association functional class: | | | | |
| NYHA class III or IV (%) | 25 | 3 | 6 | 16 |
| Atrial fibrillation (%) | 15 | 2 | 4 | 11 |
| Height of V wave (mm Hg) | 35 ± 16 | 25 ± 17 | 24 ± 7 | 41 ± 14 |
| EF (%)          | 54 ± 14         | 57 ± 10         | 53 ± 13         | 53 ± 15         |
| LA (mm)         | 34 ± 9          | 45 ± 10*        | 52 ± 9          | 55 ± 8*         |
| Echocardiographic jet type (%) | 37 | 6 | 9 | 22 |

*p < 0.05, 2+ versus 3+, 3+ versus mean (2+). 4+ versus mean. EF = ejection fraction; LA = left atrium; NYHA class = New York Heart Association functional class; MR = mitral regurgitation; V wave = pulmonary capillary wedge pressure.
Table 2. Relation Between Mitral Regurgitation as Determined by Transesophageal Color Flow Mapping and Left or Right Pulmonary Venous Flow Pattern, in 50 Patients

<table>
<thead>
<tr>
<th>Severity of Mitral Regurgitation</th>
<th>2+</th>
<th>3+</th>
<th>4+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>10</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>Reversed systolic flow</td>
<td>0</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>Blunted systolic flow</td>
<td>5</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Normal flow</td>
<td>5</td>
<td>18</td>
<td>0</td>
</tr>
</tbody>
</table>

All data are expressed as number of patients.

Transesophageal color flow imaging. Twenty-eight patients (56%) had 4+ mitral regurgitation. 12 (24%) had 3+ regurgitation and 10 (20%) had 2+ regurgitation by color flow mapping. All patients with 4+ mitral regurgitation had jet vortex formation or swirling. Adequate pulmonary venous flow tracings of the left upper pulmonary vein were obtained in 49 (98%) of the 50 patients and adequate recordings of the right upper pulmonary vein were obtained in 38 (76%).

Pulmonary venous flow patterns. Venous flow patterns in one or both upper pulmonary veins and quantitative flow velocities, associated with each grade of regurgitation as determined from color flow mapping, are shown in Tables 2 and 3. Of the 28 patients with 4+ mitral regurgitation, 26 (93%) had reversed systolic flow; 11 (92%) of 12 with 3+ regurgitation had blunted systolic flow and 5 (50%) of 10 with 2+ regurgitation had normal pulmonary venous flow (Fig. 3 and 4). The two patients with 4+ mitral regurgitation without reversed systolic flow had a central regurgitant jet.

A significant difference was found between the peak systolic flow velocity in patients with 4+ and that in patients with 2- or 3+ mitral regurgitation. Similarly, a significant difference was detected between the systolic/diastolic velocity ratio in patients with 4+ and that in patients with 2+ or 3+ regurgitation as well as between patients with 2+ versus 3+ mitral regurgitation. There was no significant difference

Table 3. Relation Between Mitral Regurgitation as Determined by Transesophageal Color Flow Mapping and Peak Left (n = 49) and Right (n = 38) Pulmonary Venous Systolic and Diastolic Flow Velocities

<table>
<thead>
<tr>
<th>Degree of Mitral Regurgitation</th>
<th>2+</th>
<th>3+</th>
<th>4+</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients with L/R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak flow velocity (cm/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left systolic (S)</td>
<td>41 ± 29</td>
<td>39 ± 24</td>
<td>43 ± 16</td>
</tr>
<tr>
<td>Right systolic</td>
<td>53 ± 19</td>
<td>53 ± 18</td>
<td>53 ± 17</td>
</tr>
<tr>
<td>Left diastolic (D)</td>
<td>43 ± 15</td>
<td>63 ± 26</td>
<td>59 ± 14</td>
</tr>
<tr>
<td>Right diastolic</td>
<td>51 ± 17</td>
<td>52 ± 27</td>
<td>61 ± 25</td>
</tr>
<tr>
<td>Peak systolic/diastolic (S/D)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow ratios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>1.0 ± 0.5*</td>
<td>0.6 ± 0.4*</td>
<td>0.2 ± 0.3*</td>
</tr>
<tr>
<td>Right</td>
<td>1.2 ± 0.5*</td>
<td>0.8 ± 0.6*</td>
<td>0.03 ± 0.1*</td>
</tr>
</tbody>
</table>

*p < 0.05 peak S, D; S/D ratio for 2+ versus 3+ mitral regurgitation; 
*tp < 0.05 peak S, D; S/D ratio for 3+ versus 4+ mitral regurgitation; 
*p< 0.05 peak S, D, S/D ratio for 2+ versus 4+ mitral regurgitation; 
*tp < 0.05 peak S, D, S/D ratio for 4+ versus 3+ mitral regurgitation. L/R = adequate recordings of the left and the right upper pulmonary vein, respectively.
in the peak diastolic flow velocities for the different grades of mitral regurgitation.

**Sensitivity and specificity.** The sensitivity of reversed systolic flow in the detection of 4+ mitral regurgitation by transesophageal color flow mapping was 83% and the specificity was 89%. The specificity of either reversed or blunted systolic flow, or both, was 90%. The sensitivity of either reversed or blunted systolic flow in transesophageal color flow mapping was 93% and the specificity was 100%. The sensitivity of blunted systolic flow in patients undergoing mitral valve repair was 89% and the specificity was 81%.

**Right versus left pulmonary vein.** Of the 38 patients who had adequate recordings of both right and left upper pulmonary veins, 9 (24%) had discordant pulmonary venous flow patterns. By color flow mapping, seven (73%) of these nine patients had 4+ mitral regurgitation and reversed systolic flow only in the right pulmonary vein. No patient had reversed systolic flow only in the left pulmonary vein. Five of these seven patients had an eccentric jet with an anteromedial jet direction (directed toward the right upper pulmonary vein) secondary to a posterior flail leaflet and two patients had a jet with central direction from various causes. Of the two other patients with discordant flow and 2+ or 3+ mitral regurgitation, both had normal flow in the right pulmonary vein with mild blunted systolic flow in the left pulmonary vein. The 12 patients without measurable flow in the right pulmonary vein did not differ from the 26 who had measurable flow with respect to jet direction, left atrial size or cause or severity of mitral regurgitation.

**Factors affecting reversed systolic flow.** The 26 patients with reversed systolic flow had a higher prevalence of atrial fibrillation (\(p = 0.05\)), a larger left atrial size (55 ± 8 vs. 49 ± 10 mm; \(p = 0.01\)) and higher absolute height of the V wave (42 ± 14 vs. 24 ± 12 mm Hg; \(p < 0.05\)) than did the 24 patients without reversed systolic flow. These groups did not differ in terms of ejection fraction, fractional shortening or jet direction. When patients with atrial fibrillation were excluded from analysis, there was still a significant difference in peak systolic flow velocity (\(p < 0.001\)) and systolic to diastolic flow velocity ratio (\(p < 0.001\)) in patients with different grades of mitral regurgitation.

**Intraoperative group.** The change from prebypass to postbypass peak left pulmonary venous flow velocities in 24 patients undergoing mitral valve repair are shown in Table 6. In the prebypass study, all 22 patients with 3+ or 4+ mitral regurgitation had either reversed or blunted systolic flow and increased diastolic flow (Fig. 5). The two patients with 2+ mitral regurgitation showed a normal flow pattern in the prebypass study. In the postbypass study, all 22 patients with 3+ or 4+ mitral regurgitation before bypass showed normalization of systolic flow and the 2 patients with 2+ mitral regurgitation showed no change compared with the prebypass study. Similarly, the diastolic flow was decreased in the postbypass compared with the prebypass study in the
Table 6. Relation Between the Change in Peak Left Pulmonary Venous Systolic and Diastolic Flow Before (prebypass) and After (postbypass) Mitral Valve Repair in 24 Patients

<table>
<thead>
<tr>
<th>Degree of Mitral Regurgitation</th>
<th>2+</th>
<th>3+</th>
<th>4+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak systolic (S) (postbypass minus prebypass) velocity</td>
<td>24 ± 10</td>
<td>-9 ± 4</td>
<td>46 ± 31</td>
</tr>
<tr>
<td>Peak diastolic (D) (postbypass minus prebypass) velocity</td>
<td>-16 ± 7</td>
<td>-13 ± 7</td>
<td>17 ± 21</td>
</tr>
<tr>
<td>Systolic/diastolic (S/D) (postbypass minus prebypass) velocity ratio</td>
<td>0.8 ± 0.4</td>
<td>0.5 ± 0.3</td>
<td>1.5 ± 0.5</td>
</tr>
</tbody>
</table>

*p < 0.05 peak S velocity, S/D ratio (postbypass minus prebypass) for 1+ versus 4+ mitral regurgitation; *p < 0.05 peak S velocity, S/D ratio (postbypass minus prebypass) for 4+ mitral regurgitation versus mean 1+, 2+, 3+ mitral regurgitation.

22 patients. There was no difference in heart rate in the postbypass compared with the prebypass study for the different grades of mitral regurgitation.

Discussion

Pulmonary venous flow is pulsatile and intrinsically related to left atrial pressure, mitral valve function and left ventricular compliance (10-12, 21, 22, 24-26). Abnormalities of pulmonary venous flow have been described in various diseases (21-29), including restrictive myocardial diseases (21, 28, 29), constrictive pericarditis (30), dilated cardiomyopathy (12), arrhythmias (11) and pulmonary venous obstruction (31, 32).

Pulmonary venous flow in mitral regurgitation. Our study clearly demonstrates that pulmonary venous flow as assessed by pulsed wave Doppler transesophageal echocardiography is influenced by the severity of mitral regurgitation. We found a spectrum of pulmonary venous flow patterns in patients with mitral regurgitation as determined by either transesophageal color flow mapping or cardiac catheterization.

Reversed systolic flow was detected in 26 of 28 patients with 4+ mitral regurgitation as assessed by transesophageal color flow mapping, yielding excellent sensitivity and specificity values of 93% and 100%, respectively. Reversed systolic flow was detected in 19 of 22 patients with 4+ mitral regurgitation as assessed by cardiac catheterization, giving good sensitivity and specificity values of 86% and 81%, respectively. The presence of reversed systolic flow was useful in differentiating 4+ and 3+ mitral regurgitation. For the detection of 4+ mitral regurgitation, the differences in sensitivity and specificity between transesophageal color flow mapping and cardiac catheterization most likely reflect the fact that the procedures were not simultaneous and were performed under different loading conditions. Because color flow mapping was done at the same time as pulsed wave Doppler echocardiography and was graded independently, those sensitivities and specificities are likely to be more accurate. Blunted or decreased systolic flow was detected in

Figure 5. Pulsed wave Doppler transesophageal recording of the left upper pulmonary vein in an 81-year-old woman with 4+ mitral regurgitation (MR) (upper) and a 71-year-old man with 3+ mitral regurgitation (lower). Note the reversed systolic flow (RSF) (left upper) and blunted systolic flow (left lower) in the prebypass (PRE-PUMP) study and "normalization" of pulmonary venous systolic flow in the postbypass (POST-PUMP) study (right upper and right lower). Abbreviations as in Figure 3.
11 (92%) of 12 patients with 3+ mitral regurgitation as assessed by transesophageal color flow mapping, but in only 4 (40%) of 10 patients with 3+ mitral regurgitation as determined by cardiac catheterization. Once again, the differences probably reflect the non-simultaneous timing of the two techniques. Nevertheless, blunted systolic flow was not sensitive (61%) but was specific (97%) for detecting 3+ mitral regurgitation by transesophageal color flow mapping.

Normal equaphasic pulmonary venous flow was detected in only 5 (50%) of 10 patients with 2+ mitral regurgitation as determined by transesophageal color flow mapping and in only 3 (25%) of 12 patients with 2+ regurgitation as determined by cardiac catheterization. These findings can be explained by possible limitations in the grading techniques of color flow mapping or cardiac catheterization, with overlap in mitral regurgitation grades between 2+ and 3+ in our study group. The combination of reversed and blunted systolic flow was useful in differentiating clinically significant mitral regurgitation (3+ or 4+) from clinically insignificant mitral regurgitation (2+) by transesophageal color flow mapping; however, the number of patients in the latter group was small (n = 10).

Intraoperative studies. The influence of mitral regurgitation on pulmonary venous flow was also apparent in the intraoperative group. These 24 patients were tested twice: prebypass (before mitral valve repair) and postbypass (after mitral valve repair). Twenty-two of these patients with 3+ or 4+ mitral regurgitation before bypass showed normalization of flow, with an increase in peak systolic forward pulmonary venous flow velocity after repair of the mitral regurgitant leak, regardless of the cause of the leak (19), whereas two patients with 2+ mitral regurgitation with normal flow before bypass showed no significant change in the postbypass study.

Differences between right and left pulmonary veins. We found discordant flow in the right and left upper pulmonary veins in 9 (24%) of 38 patients, of whom 78% had 4+ mitral regurgitation. Systolic flow was usually blunted in the left pulmonary vein and reversed in the right pulmonary vein. Thus, if only the left pulmonary vein was sampled and if the flow patterns were used to predict severity, the severity of 4+ mitral regurgitation would be underestimated. The mechanism for the discordant flow may be related to various factors, including differential flow directed to the pulmonary vein secondary to an eccentric jet, left atrial size and left atrial volume (33,34).

A potential bias in the study is that most of the patients with 4+ mitral regurgitation had a posterior flail leaflet with an anterior jet direction, whereas most other patients had an anterior flail leaflet and a posterolateral jet direction. Also, sampling the right pulmonary vein is more difficult than sampling the left pulmonary vein with the standard transverse imaging planes.

Factors influencing reversed systolic flow. Patients with reversed systolic flow had a larger left atrium as measured by transthoracic echocardiography, a larger V wave and a higher incidence of atrial fibrillation than did patients without reversed flow. Thus, reversed systolic flow was present even in patients with a large left atrium.

Mechanisms. The reversed systolic flow indicated by Doppler echocardiography can be considered analogous to the systolic reflux of contrast dye seen during angiography in patients with 4+ mitral regurgitation. It is also similar to the reversed systolic flow in the hepatic vein that is found by Doppler echocardiography in patients with 4+ tricuspid regurgitation (35). Reversed systolic flow was present in patients with a larger V wave in the pulmonary venous diastolic flow recordings are inversely related to the left atrial pressure tracing. In a preliminary study (37), we found that the normal, blunted and reversed systolic flow patterns in the pulmonary vein are directly related to left atrial pressure A and V waves and A-x and V-y descents and that reversed systolic flow is directly related to the V wave amplitude in patients with mitral regurgitation (Fig. 6).

Previous studies. In two preliminary reports (38,39) assessing the influence of mitral regurgitation on pulmonary venous flow, the investigators concluded that pulmonary venous flow is useful in differentiating mild from significant mitral regurgitation. Other investigators (10-12,40,41) have shown that factors such as left ventricular dysfunction, arrhythmias (including atrial fibrillation) and the effect of loading conditions, may also influence pulmonary venous flow. Kuecherer et al. (42) recently identified a relation...
systolic flow (RSF) with initial regurgitation. AR - peak pulmonary venous diastolic flow velocity.

between a mean left atrial pressure > 15 mm Hg and blunted pulmonary venous systolic flow in patients without mitral regurgitation and suggested that pulmonary venous flow recordings may be used for noninvasive assessment of left atrial pressure.

Limitations. A major limitation of our study was the lack of simultaneous hemodynamic and angiographic data in the pulmonary venous flow recordings. This lack surely influenced the discrepancy between transesophageal color flow mapping and angiographic assessment of mitral regurgitation. Nevertheless, the high sensitivities and specificities in detecting reversed systemic flow are remarkable, especially because of the time lapse between the two measurements.

We did not distinguish between systemic turbulence in the pulmonary vein and laminar reversal of flow. Thus, we did not quantify the reversed flow, although we attempted to place the pulsed wave Doppler sample volume into the pulmonary vein beyond the turbulence. Atrial fibrillation may have also played a major role in influencing the pulmonary venous recordings because it is known to cause blunted systemic flow in patients without mitral regurgitation (12). When patients with atrial fibrillation were excluded from the analysis, there was still a difference in the peak systemic flow velocity and the systemic/diastolic flow velocity ratio between patients with 4+ and those with 2- and 3+ mitral regurgitation.

Clinical implications. This study illustrates the effect of increasing severity of mitral regurgitation on pulmonary venous flow. The pulmonary venous flow patterns, ranging from normal to blunted to reversed systemic flow, may be potential physiologic predictors of the severity of mitral regurgitation (Fig. 7). A useful implication is that pulmonary venous flow recordings may help differentiate 2+ from 3+ and 4+ mitral regurgitation, especially when the severity of mitral regurgitation determined from color flow mapping or cardiac catheterization is not clear. This ability may be especially important in the operating room when the echocardiographer is called on to assess the physiologic significance of any residual mitral regurgitation during mitral valve repair (9, 30).

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References


