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To clarify the role of color Doppler echocardiography in the evaluation of mitral valve prolapse, we studied 49 consecutive patients in whom the sites of mitral valve prolapse were confirmed at the time of operation. The study group consisted of 22 patients with anterior leaflet prolapse, 24 patients with posterior leaflet prolapse, and three patients with multiple scallop prolapse (one patient with both anterior leaflet and middle scallop prolapse, and two patients with both medial and lateral scallop prolapse). Two-dimensional echocardiographic diagnosis of anterior leaflet prolapse was correct in all patients. The diagnosis of posterior leaflet prolapse by two-dimensional echocardiography, however, was mistaken as anterior leaflet prolapse in 16 (13 patients with medial scallop prolapse and three patients with lateral scallop prolapse) of the 24 patients according to current diagnostic criteria for mitral valve prolapse. Eight patients with middle scallop prolapse were diagnosed correctly by two-dimensional echocardiography. Acceleration flows in the left ventricle were observed by color Doppler echocardiography in all 49 patients. The sites of acceleration flows detected by color Doppler echocardiography coincided with those of prolapse confirmed in all at the time of operation. There was a significant correlation between the maximum area of acceleration flow signals and severity of mitral regurgitation estimated by angiography. In the three patients with posterior leaflet prolapse and the three patients with lateral scallop prolapse, a regurgitant jet originated from a bulged portion of the posterior leaflet and was directed toward the opposite side of the left atrial cavity to the bulged portion by short-axis images of color Doppler echocardiography. In the remaining patients with single prolapse, a regurgitant jet in the left atrium was directed toward the left atrial cavity opposite to the prolapsed scallop. In three patients with multiple scallop prolapse, it was difficult to determine the direction of the regurgitant jet by color Doppler echocardiography because of multiple regurgitant jets in the left atrium. In these three patients, however, two acceleration flows in the left ventricle were detected, and the sites of acceleration flows coincided with those of prolapse confirmed at the time of surgery. Thus, information on acceleration flows and direction of regurgitant jets detected by color Doppler echocardiography is useful in the detection of the site of mitral valve prolapse. (*Circulation* 1990;81:879–885)

Two-dimensional echocardiography has been proven useful in the detection of mitral valve prolapse.1-9 As the clinical experience has grown, however, limitations in the specificity of two-dimensional echocardiography for the diagnosis of this disorder have been demonstrated.5,7 Further-

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Methods
The analysis of the two-dimensional echocardiographic and color Doppler echocardiographic data on all patients undergoing surgical correction of pure mitral regurgitation at Kobe General Hospital, Kobe, Japan, forms the basis of this report. Patients with mitral stenosis or combined mitral stenosis and insufficiency were excluded from the study. During a 3-year study period, 61 patients underwent surgical therapy for pure mitral insufficiency. Forty-nine of 61 patients had the anatomic finding of mitral valve prolapse at the time of operation, and these 49 patients were examined by two-dimensional and color Doppler echocardiography. There were 28 men and 21 women (age, 42–69 years; mean, 56 years). At the time of operation, mitral regurgitation was evaluated by manual injection of saline solution into the arrested left ventricle with a cannula introduced through the aortic valve. The atrial aspect of the mitral valve was visually inspected for the site of leakage. After gross examination by the cardiac surgeon, the cardiologist and the pathologist examined all valves. To aid the pathologist in distinguishing ruptured chordae tendineae from chordae that had been cut during surgical procedure, the surgeon placed a metal clip across the base of chordae that had been found ruptured at operation. The sites of the anterior leaflet prolapse were divided into three parts—medial, middle, and lateral portions. The sites of posterior leaflet prolapse were divided into three parts—medial scallop, middle scallop, and lateral scallop. The study group consisted of 22 patients with anterior leaflet prolapse (10 patients with prolapse at the medial portion, nine patients with prolapse at the central portion, and three patients with prolapse at the lateral portion), 24 patients with posterior leaflet prolapse (13 patients with medial scallop prolapse, eight patients with middle scallop prolapse, and three patients with lateral scallop prolapse), and three patients with multiple scallop prolapse (one patient with both anterior leaflet prolapse and middle scallop prolapse, and two patients with both medial and lateral scallop prolapse).

Two-Dimensional Echocardiography
Two-dimensional echocardiographic studies were performed using either an Aloka SSD-880 (Tokyo, Japan) or a Toshiba SSH-65A (Tokyo, Japan) and a 2.5- or 3.5-MHz transducer. The integrity of the mitral apparatus was evaluated using the parasternal long- and short-axis views, apical long-axis, and four-chamber views. The presence or absence of mitral valve prolapse was determined using previously published criteria.5

Color Doppler Echocardiography
Color Doppler examinations were performed with a commercially available system (Toshiba SSH-65A) and a 2.5-MHz transducer. The studies were performed using a 45° color sector at a 4-kHz pulse-repetition frequency that allowed measurement of velocities up to 75 cm/sec, with a scanning rate of 12 frames/sec. Flow directed toward the transducer is conventionally coded in red, whereas flow directed away is coded blue. Variations in velocity are presented by brightness and intensity of color. Because the color Doppler system is based on a pulse mode, the magnitude of flow velocity is limited in all points of the ultrasound sector. If turbulence occurs, green is added to the red or blue underlying color, thus changing the basic color tonality, with a resulting mosaic pattern. Doppler color gain was optimized as described previously.20 Pictures were obtained with a Polaroid camera placed in front of a color TV monitor. Doppler windows used were parasternal long-axis and short-axis views and apical long-axis and four-chamber views. Acceleration flow signals were presented as a homogeneous bluish-green flow with a central zone that is colored in yellow because of the aliasing of the Doppler frequencies. When the acceleration flow signals were identified, care was taken to detect the maximum area of acceleration flow signals by shifting and tilting the transducer. Direction of the mitral regurgitant jet was defined as indicated in Figure 1.

To evaluate the correlation between acceleration flow signals and severity of mitral regurgitation, the area of acceleration flow signals was measured in 51 consecutive patients who underwent left ventriculography. To compute the maximum area of acceleration flow signals with orthogonal planes, videotapes were carefully analyzed frame by frame. With a software program already incorporated in the equipment, the outline of acceleration flow signals was traced with a joystick, and the area was measured by computerized planimetry. If more than one acceleration flow were visualized, they were added for calculation of lesion severity. The maximum area of acceleration flow signals, which was obtained by measuring the largest area of those obtained from three orthogonal planes, was compared with angiographic gradings.

Left ventriculograms for comparison were evaluated by a cardiologist who did not know the Doppler echocardiographic findings, and the severity of mitral regurgitation was graded according to the classifica-

![Figure 1. Schematic diagram of definitions used for direction of mitral regurgitant jet by short-axis view. 1, posterior and lateral; 2, posterior and central; 3, posterior and medial; 4, posterior and lateral; 5, lateral; 6, anterior and central; 7, posterior and medial; 8, medial; AML, anterior mitral leaflet.](http://circ.ahajournals.org/DownloadedFrom)[Figure 1. Schematic diagram of definitions used for direction of mitral regurgitant jet by short-axis view. 1, posterior and lateral; 2, posterior and central; 3, posterior and medial; 4, posterior and lateral; 5, lateral; 6, anterior and central; 7, posterior and medial; 8, medial; AML, anterior mitral leaflet.](http://circ.ahajournals.org/DownloadedFrom)
tion of Sellers et al,22 that is, 1+ (mild), 2+ (moderate), 3+ (moderate to severe), and 4+ (severe).

In the statistical analysis of the results, the significance of the differences between the mean values was assessed by the Student's t test. Observer variability in the subjective assessment of the presence or absence of acceleration flow signals and in the quantitative assessment of the area of acceleration flow signals in our laboratory has been determined in 40 randomly selected patients. From the accumulated data, there was no interobserver or intraobserver variability in the subjective assessment of the presence or absence of acceleration flow signals. The average intraobserver variability for the quantitative assessment of the area of acceleration flow signals was 2.7% of the mean value, and the average interobserver variability was 4.6% of the mean.

Results

Anterior Leaflet Prolapse

The diagnosis of the presence as well as the site of mitral valve prolapse was made by two-dimensional echocardiography in all 22 patients. Acceleration flows in the left ventricle (Figure 2) were observed in all 22 patients by color Doppler echocardiography. The site of acceleration flows detected by color Doppler echocardiography coincided with the site of prolapse confirmed at the time of operation in all (Table 1). The regurgitant jet was directed toward the posterolateral portion of the left atrium in all patients with mitral valve prolapse at the medial portion of the anterior leaflet (Table 2), toward the posterior and central left atrial cavity in all patients with mitral valve prolapse at the central portion of the anterior leaflet, and toward the posterior and medial portion of the left atrium in all patients with mitral valve prolapse at the lateral portion of the anterior leaflet.

Posterior Leaflet Prolapse

The diagnosis of the presence of mitral valve prolapse was made in all 24 patients by two-dimensional echocardiography. With regard to the site of prolapse, however, two-dimensional echocardiography by current diagnostic criteria misread 16 (13 patients with medial scallop prolapse and three patients with lateral scallop prolapse) of 24 patients with posterior leaflet prolapse as having anterior leaflet prolapse. Eight patients with middle scallop prolapse were diagnosed correctly by two-dimensional echocardiography. On the other hand, color Doppler echocardiography revealed acceleration

<table>
<thead>
<tr>
<th>TABLE 1. Comparison Between Site of Acceleration Flow Estimated by Color Doppler and That Estimated at Time of Surgery in 22 Patients With Anterior Leaflet Prolapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site of prolapse at surgery</td>
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<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>Medial portion</td>
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<tr>
<td>Medial portion</td>
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</tbody>
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<tr>
<th>TABLE 2. Site of Acceleration Flow and Direction of Mitral Regurgitant Jet Estimated by Color Doppler Echocardiography in 22 Patients With Anterior Leaflet Prolapse</th>
</tr>
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<tbody>
<tr>
<td>Site of acceleration flow</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>Direction of MR jet</td>
</tr>
<tr>
<td>Posterior and lateral</td>
</tr>
<tr>
<td>Posterior and central</td>
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<tr>
<td>Posterior and medial</td>
</tr>
</tbody>
</table>

MR, mitral regurgitation.
flows (Figure 3) at the site of prolapsed scallop in all patients. The site of acceleration flows detected by color Doppler echocardiography coincided with the site of prolapse confirmed in all at the time of operation (Table 3). In 13 patients with medial scallop prolapse, a regurgitant jet was directed toward lateral left atrial cavity in 11 patients and toward the posterior and lateral portion of the left atrium in two patients (Table 4). In three patients with lateral scallop prolapse, a regurgitant jet was directed toward the medial portion of the left atrium in two patients and toward the posterior and medial portion of the left atrium in one. A regurgitant jet was directed toward the anterior and central left atrial cavity in all eight patients with middle scallop prolapse.

Multiple Scallop Prolapse

In two patients with both medial and lateral scallop prolapse, the diagnosis of the presence of mitral valve prolapse was made by two-dimensional echocardiography but the site of prolapse was misdiagnosed as anterior leaflet prolapse. In one patient with anterior leaflet prolapse and middle scallop prolapse, sites of prolapse were diagnosed correctly by two-dimensional echocardiography. In these three patients, two acceleration flows in the left ventricle were observed (Figure 4) by color Doppler echocardiography, and the sites of acceleration flows coincided with the sites of prolapse confirmed at the time of surgery. It was difficult, however, to determine the correct direction of the regurgitant jet by color Doppler echocardiography because of multiple regurgitant jets in the left atrium in patients with multiple scallop prolapse.

Relation Between the Area of Acceleration Flow Signals and Severity of Mitral Regurgitation

Individual values of the maximum area of acceleration flow signals for 12 patients with 1+ mitral regurgitation by angiography were in the range of 0-41 mm² (mean, 13±11 mm²). In nine patients with 2+ regurgitation by angiography, the maximum area of acceleration flow signals was in the range of 4-128 mm² (mean, 48±47 mm²), whereas the maximum area of acceleration flow signals in 10 patients with 3+ regurgitation was in the range of 76-212 mm² (mean, 143±48 mm²). Individual values of the maximum area of acceleration flow signals for 10 patients with 4+ mitral regurgitation by angiography were in the range of 102-241 mm² (mean, 179±40 mm²). The maximum area of acceleration flow signals correlated well with the angiographic grade of

TABLE 3. Comparison Between Site of Acceleration Flow Estimated by Color Doppler and That Estimated at Time of Surgery in 24 Patients With Posterior Leaflet Prolapse

<table>
<thead>
<tr>
<th>Site of prolapse at surgery</th>
<th>Medial scallop</th>
<th>Middle scallop</th>
<th>Lateral scallop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial scallop</td>
<td>13</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Middle scallop</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Lateral scallop</td>
<td>3</td>
<td>8</td>
<td></td>
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</tbody>
</table>

TABLE 4. Site of Acceleration Flow and Direction of Mitral Regurgitant Jet Estimated by Color Doppler Echocardiography in 24 Patients With Posterior Leaflet Prolapse

<table>
<thead>
<tr>
<th>Direction of MR jet</th>
<th>Medial scallop</th>
<th>Middle scallop</th>
<th>Lateral scallop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior and lateral</td>
<td>2</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Anterior and central</td>
<td>8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Medial</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior and medial</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MR, mitral regurgitation.
mitral regurgitation (Figure 5). There was a significant difference in the maximum area of acceleration flow signals between 1+ and 2+ ($p<0.05$), 2+ and 3+ ($p<0.005$), and 3+ and 4+ mitral regurgitation ($p<0.05$).

**Discussion**

In the present study, we attempted to detect, by using color Doppler echocardiography, the origin of the mitral regurgitant jets at the mitral orifice as well as the direction of the regurgitant jet in the left atrium, and to examine the relations of the origin and direction of the regurgitant jet and the site of prolapse confirmed at surgery.

**Relation Between the Prolapsed Site and Direction of the Regurgitant Jet**

Although diagnosis in regard to the presence of mitral valve prolapse was made by using two-dimensional echocardiography in all 49 patients with mitral valve prolapse, the site of prolapse was not correct in 16 of 24 patients with posterior leaflet prolapse. Two-dimensional echocardiographic diagnosis of the site of anterior leaflet prolapse was correct in all patients, however, the diagnosis by two-dimensional echocardiography of posterior leaflet prolapse was mistaken as anterior leaflet prolapse in 16 of 24 patients, according to current diagnostic criteria for mitral valve prolapse. Color Doppler echocardiography, however, revealed a characteristic pattern of the direction of mitral regurgitation signals in patients with posterior leaflet prolapse. Short-axis images of color Doppler echocardiography showed that the regurgitant jet was directed toward the lateral portion of the left atrium in patients with medial scallop prolapse, toward the anterior portion of the left atrium in patients with middle scallop prolapse, and toward the medial portion of the left atrium in patients with lateral scallop prolapse. Thus, the diagnosis of the damaged site of the leaflets can be made from the direction of the regurgitant jet.

**Role of Acceleration Flows by Color Doppler Echocardiography**

In patients with mitral stenosis, acceleration of the blood flow is observed just proximal to the orifice; however, there are no reports regarding the role of acceleration flows in patients with valvular regurgitation. Our study demonstrated that acceleration flow signals in the left ventricle as seen by using color Doppler echocardiography are very useful in the diagnosis of the site of mitral valve prolapse. In the present study, the site of acceleration flow in the left ventricle detected by color Doppler echocardiography coincided with the site of mitral valve prolapse confirmed in all at the time of operation. On the
other hand, two-dimensional echocardiography failed to detect the correct site of prolapse in patients with medial or lateral scallop prolapse. Our data indicate that the site of acceleration flow detected by color Doppler echocardiography is the origin of regurgitation. Mitral valve prolapse often involves one or more scallops of the valves. In such cases, as multiple regurgitant jets in the left atrium were observed, it might be difficult to identify the correct direction of the regurgitation signals. Multiple acceleration flows, however, were detected by using color Doppler echocardiography, and the sites of acceleration flow detected by color Doppler echocardiography coincided with sites of valve lesions confirmed at operation. Using this technique, it appears possible to be sure of the origin of the mitral regurgitation at the mitral orifice. Therefore, the information on the site of acceleration flow, as detected by color Doppler echocardiography, is useful in the preoperative estimation of the mitral valve lesion.

Our data indicate that the area of acceleration flow signals might predict the severity of mitral regurgitation. In our experience, small variations in color gain do not produce any changes in the area of acceleration flow signals; however, an excessive decrease in the gain might produce a significant reduction in area because of the elimination of lower velocities. Additionally, a variety of technical factors inherent in the performance of Doppler color flow imaging are capable of influencing the size of acceleration flow signals, including pulse repetition frequency, frame rate, attenuation of ultrasound energy, angle of incidence, and limitations of the instrumentation to record low velocities of flow.

Clinical Implication

Echocardiography has facilitated noninvasive diagnosis of mitral valve prolapse. It can identify leaflet redundancy and abnormal systolic movement of the mitral valve above the plane of the mitral valve anulus. Although there are numerous reports in the diagnosis of the presence of mitral valve prolapse, there are few reports regarding the diagnostic value of two-dimensional echocardiography and Doppler echocardiography in the detection of the site of mitral valve prolapse and the origin of mitral regurgitant jets. The correct diagnosis of the origin of the mitral regurgitant jets in patients with mitral valve prolapse is especially important when we select reconstructive surgery of the mitral valve.

In patients undergoing reconstructive surgery of the mitral valve, indetification of anatomic lesion and site of regurgitation is an absolutely essential step.23–25 Carpentier and associates,23 who have extensive experience with mitral valvuloplasty, have classified the indications for reconstructive mitral surgery primary and relative and have also described contraindications; prolapse of the central portion of the anterior leaflet is a contraindication, prolapse of the paramedial or paralateral portion anterior leaflet is only a relative indication, and prolapse of one third or less of the posterior leaflet is a primary indication.

Two-dimensional echocardiography, because of its unique ability to provide spatial information regarding cardiac structures, shows promise for the accurate noninvasive detection in patients with mitral valve prolapse. The diagnosis of the site of prolapse, however, is sometimes difficult by this technique. Furthermore, two-dimensional echocardiography is limited in its ability to define valvular regurgitation. On the other hand, color Doppler echocardiography enables one to observe two-dimensional aspects of both anatomic lesion and blood flow abnormalities in realtime. In the present study, the overall direction and site of regurgitation in the mitral valve are closely related to the condition of the underlying valve lesion. Thus, the information on the direction and site of acceleration flow estimated by color Doppler echocardiography is useful in defining the site of regurgitation as well as any other abnormalities that might be present, and in confirming the successful repositioning of structures postoperatively.

References

pulsed Doppler spectral analysis. *Am J Cardiol* 1983; 51:1122–1127


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**KEY WORDS** • mitral valve prolapse • color Doppler flow mapping • acceleration flow • regurgitant jet direction
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