

DIAGNOSTIC TECHNIQUES

The Flail Mitral Valve: Echocardiographic Findings by Precordial and Transesophageal Imaging and Doppler Color Flow Mapping

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To determine the echocardiographic and Doppler characteristics of mitral regurgitation associated with a flail mitral valve, precordial and transesophageal echocardiography with pulsed wave and Doppler color flow mapping was performed in 17 patients with a flail mitral valve leaflet due to ruptured chordae tendineae (Group I) and 22 patients with moderate or severe mitral regurgitation due to other causes (Group II). Echocardiograms were performed before or during cardiac surgery; cardiac catheterization was also performed in 28 patients (72%). Mitral valve disease was confirmed at cardiac surgery in all patients.

By echocardiography, the presence of a flail mitral valve leaflet was defined by the presence of abnormal mitral leaflet coaptation or ruptured chordae. Using these criteria, transesophageal imaging showed a trend toward greater sensitivity and specificity than precordial imaging in the diagnosis of flail mitral valve leaflet. By

Doppler color flow mapping, a flail mitral valve leaflet was also characterized by an eccentric, peripheral, circular mitral regurgitant jet that closely adhered to the walls of the left atrium. The direction of flow of the eccentric jet in the left atrium distinguished a flail anterior from a flail posterior leaflet. By transesophageal echocardiography with Doppler color flow mapping, the ratio of mitral regurgitant jet arc length to radius of curvature was significantly higher in Group I than Group II patients (5.0 ± 2.3 versus 0.7 ± 0.6 , $p < 0.001$); all of the Group I patients and none of the Group II patients had a ratio >2.5 .

Thus, transesophageal imaging with Doppler color flow mapping of mitral regurgitation is complementary to precordial echocardiography in the diagnosis and localization of flail mitral valve leaflet due to ruptured chordae tendineae.

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Diagnostic signs of flail mitral leaflet due to ruptured chordae tendineae have been previously described (1-7) by precordial M-mode and two-dimensional echocardiography and transesophageal echocardiography. Precordial two-dimensional echocardiography has been found to be superior to M-mode findings (including systolic echo within the left atrium, systolic or diastolic flutter of the mitral leaflets, paradoxical posterior mitral leaflet motion and exaggerated mitral excursion) in the diagnosis of loss of normal systolic mitral valve coaptation (2-6). Transesophageal echocardiographic imaging of the ruptured chordal segment in the left atrium during systole may provide even greater sensitivity than precordial imaging in the detection of a flail mitral valve (7). Although a flail mitral valve is often marked by severe mitral regurgitation, characteristic patterns of mitral regurgitation by Doppler color flow mapping have not been reported in this condition.

In the evaluation of mitral regurgitation and other cardiac lesions, transesophageal echocardiography with Doppler color flow mapping has been found to be a useful test for patients in the intensive care unit or operating room. As a result of the renewed interest in surgical reconstruction of insufficient mitral valves and the belief that earlier operative intervention may prevent permanent myocardial damage (8-11), the accurate preoperative assessment of the severity and etiology of mitral regurgitation has become increasingly important. Flail mitral valve leaflet due to ruptured chordae tendineae is a lesion that usually permits successful mitral valve repair by surgeons experienced in Carpentier and Duran techniques (8-11). Because transesophageal echocardiography with Doppler color flow mapping permits high resolution imaging of mitral valve anatomy and mitral regurgitant flow, we compared this procedure with precordial echocardiography in the diagnosis and evaluation of flail mitral valve.

Methods

Patient selection (Table 1). Over a 2 year period (April 1987 to April 1989), 24 adult patients suspected of having a flail mitral valve leaflet with rupture chordae tendineae after evaluation in the echocardiography laboratory were eligible

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Table 1. Clinical Characteristics of 39 Study Patients With Mitral Regurgitation

	Group I (flail) (n = 17)	Group II (non-flail) (n = 22)
Mean age (yr)	57	55
Etiology of mitral valve disease		
Bacterial endocarditis	5	3
Myxomatous disease	5	2
Spontaneous chordal rupture	5	0
Severe mitral annular calcification	2	1
Rheumatic disease	0	8
Ischemic heart disease	0	4
Primum ASD with cleft mitral valve	0	3
Abnormal anteromedial mitral scallop	0	1
Cardiac surgery		
Mitral valve repair	10	5
Mitral valve replacement	7	14
Commissurotomy	6	3
Coronary artery bypass	2	3
Patch closure of ASD	0	2
AoV replacement	0	1
TV repair	0	1

ASD = atrial septal defect, AoV = aortic valve, TV = tricuspid valve.

for this study. Of these patients, 17 had confirmation of findings at cardiac surgery and constitute Group I; their mean patient age was 57 years (range 35 to 72) and 11 were male. Cardiac surgical procedures and etiologies of ruptured chordae are listed in Table 1. Two Group I patients had significant coronary artery disease and also underwent coronary artery bypass surgery at the time of mitral valve surgery. Patients underwent precordial and transesophageal echocardiography with Doppler color flow mapping before (within 2 weeks) or during cardiac surgery. Of the 17 Group I patients, 9 underwent intraoperative and 8 ambulatory transesophageal studies; all 17 patients underwent ambulatory precordial studies.

Over the same time period, a control group of 22 patients with moderate or severe mitral regurgitation due to other causes (Group II) underwent precordial and transesophageal echocardiography with Doppler color flow mapping before or during mitral valve surgery. Of the 22 Group II patients, 17 underwent intraoperative and 5 ambulatory transesophageal echocardiograms; all precordial studies were ambulatory. Etiologies of mitral valve disease and types of mitral valve surgery for Group II patients are listed in Table 1. Mean patient age was 55 years (range 25 to 86); 18 were female. Other cardiac lesions associated with mitral regurgitation in these 22 patients included rheumatic mitral stenosis in 6, coronary artery disease in 4 (3 also underwent coronary artery bypass grafting at the time of mitral valve surgery), primum atrial septal defect in 3 (2 also underwent patch closure of the defect at the time of mitral valve repair) and severe aortic and tricuspid insufficiency in 1 who underwent concomitant aortic valve replacement and tricuspid valvuloplasty. Mitral stenosis was defined by the presence of

typical clinical and echocardiographic features, including diastolic rumble by auscultation and evidence of thickened mitral leaflets, limited valvular motion and characteristic Doppler pattern by echocardiography.

Echocardiographic Imaging

Precordial and transesophageal echocardiograms were performed with a commercially available HP model 77020 AC echocardiograph and HP model 21312A transesophageal echocardiography probe. All echocardiograms were interpreted and measured by two observers who were blinded to the patients' diagnosis.

Precordial echocardiography. Conventional parasternal, apical and subcostal views were obtained by several technicians and recorded on 1/2 inch videotape. By two-dimensional echocardiography, criteria for the diagnosis of flail mitral valve included the presence of a ruptured chord or abnormal coaptation of the mitral leaflets in systole (2-7).

Pulsed wave and Doppler color flow mapping (2.5 MHz transducers) of mitral regurgitation was performed in all standard views. To localize the mitral regurgitant flow, the pulsed wave Doppler cursor was placed at the tips of the mitral valve leaflets and moved posteriorly throughout the left atrium. The severity of mitral regurgitation by pulsed wave Doppler echocardiography was determined semiquantitatively by the extent of penetration of the mitral regurgitant signal into the left atrium during systole (12).

Doppler color flow mapping of mitral regurgitation was also performed in all standard views. The primary colors of red and blue were superimposed on a two-dimensional echocardiographic image and used to express direction, velocity and aliasing of blood flow. According to convention, red was assigned to represent flow toward the transducer and blue to represent flow away from the transducer. Color brightness was proportional to velocity up to the Nyquist limit (13,14). When velocity was greater than these limits, the aliasing phenomenon occurred and the opposite color was assigned. Studies were performed at frame rates of 15 to 30/s, depending on the width of the color flow sector scan and the depth of imaging. In the evaluation of mitral regurgitation, Doppler color flow gain was adjusted to a level just below excessive random noise. Minor adjustments in transducer angle were made to maximize the area of penetration of mitral regurgitation into the left atrium during systole. In the case of an eccentric mitral regurgitant jet, the angle of the transducer was altered slightly to maximize the arc of penetration around the left atrium. When the entire regurgitant jet and left atrium could not be encompassed in a single sector scan, "off-axis" parasternal and two and four chamber views were employed.

Transesophageal echocardiography. Transesophageal imaging was performed with a commercially available 5 MHz, 64 element, phased array imaging crystal incorporated into a 9 mm adult gastroscope (HP model 21312A probe) interfaced with an HP model 77020 AC echocardiograph. After in-

formed consent was obtained, transesophageal echocardiograms were performed either intraoperatively (26 patients; 9 in Group I and 17 in Group II) or preoperatively on an ambulatory basis (13 patients).

For the ambulatory studies, patients were instructed to fast for ≥ 4 h; systemic sedation was usually avoided. Local anesthesia of the hypopharynx was first achieved by having the patient gargle and swallow, in divided aliquots, 4% viscous lidocaine diluted 10 to 1 in 50 ml of saline solution. The back of the patient's throat was then repeatedly sprayed with aerosolized 10% lidocaine. After the gag reflex was adequately suppressed, the patient was placed in the left lateral recumbent position, the esophageal probe was introduced, a bite block was placed to protect the probe and the patient's teeth and the patient facilitated passage of the probe by swallowing. Intermittent suctioning of secretions was performed as needed. Patients were monitored by a single electrocardiographic lead displayed on the echocardiograph monitor, and blood pressures were taken at baseline and throughout the procedure. For the intraoperative studies, the probe was introduced into the esophagus after endotracheal intubation. In the operating room, customary monitoring techniques were employed.

Standard transesophageal views in the long axis, four chamber and short axis of the left ventricle and aortic valve and in the short axis of the ascending and descending aorta were obtained both for imaging and Doppler color flow mapping (15,16). These, as well as "off-axis" angulated four chamber views, were obtained by gentle probe advancement and withdrawal, manipulation of the anteroposterior and lateral flexion controls, as well as axial torque rotation of the shaft. The area of interest was imaged at the largest possible scale to maximize the color frame rate and resolution of imaging.

Classification of mitral regurgitation by Doppler color flow mapping. Mitral regurgitant color flow jets were categorized as "eccentric" or "central" on the basis of the shape of the jet and its pattern of penetration into the left atrium. Eccentric color flow mitral regurgitant jets were peripheral, circular and closely adherent to the inner walls of the left atrium (Fig. 1). Central jets were "flame-shaped," directed into the middle portion of the left atrium and neither closely adherent to the walls of the left atrium nor circular. In the standard (15,16) transesophageal echocardiographic four chamber view (left atrium at the top of the screen, atrial septum at the left side of the screen), the direction of an eccentric mitral regurgitant jet was defined as clockwise or counterclockwise. When the entire mitral regurgitant color flow jet, left atrium and surrounding structures could not be encompassed in a single sector scan, adjacent sectors at the same level were imaged sequentially.

Measurement of arc length and radius of curvature of a mitral regurgitant jet. For the transesophageal studies, the arc length of the mitral regurgitant color flow jet was measured in the following fashion. After videotape review, the video frame demonstrating the greatest penetration of

the mitral regurgitant jet into the left atrium was selected and traced onto tracing paper. A standard set of artist French curves was used to fit and bisect the traced jet. The length of this "best fit" curve was then measured using a flexible ruler (C-THRU 1261). The radius of curvature of this mitral regurgitant color flow jet was determined by constructing two chords to the arc, bisecting the chords with perpendicular lines and measuring the distance from the arc to the intersection of the two bisecting lines.

Cardiac catheterization. Cardiac catheterization was performed in 11 of 17 Group I and 17 of 22 Group II patients. The severity of mitral regurgitation (0 to 4+) was assessed semi-quantitatively on the basis of left atrial opacification during ventriculography (17). All patients who underwent ventriculography had mitral regurgitation of at least grade 2+ in severity (5 patients 2+, 7 patients 3+ and 14 patients 4+).

Etiology of mitral valve disease. All patients in the study underwent cardiac surgery that involved surgical inspection of the mitral valve. Descriptions of the mitral valve were taken from operative and pathologic reports. The diagnosis of flail mitral valve leaflet was based on the finding of ruptured chordae tendinae at the time of surgical inspection. Similar to previous work (18-23), criteria for the diagnoses of rheumatic, ischemic, myxomatous, congenital and other mitral valve diseases were based on the results of clinical evaluation, precordial and transesophageal echocardiography, cardiac catheterization and surgical inspection.

Statistics. Data on patients in Group I and Group II were compared by chi-square analysis and Student's *t* test for independent means. Statistical significance was assumed at the 5% level. Intra- and interobserver variability for the ratio of arc length to radius of curvature was calculated as the average percent difference between sets of measurements.

Results

Echocardiographic findings of flail mitral valve leaflet by precordial and transesophageal imaging (Table 2). Imaging characteristics that were significantly more common in Group I than in Group II patients by precordial or transesophageal echocardiography included abnormal coaptation of mitral leaflets (Fig. 1A) and ruptured chordae (Fig. 2). By precordial echocardiography, abnormal mitral leaflet coaptation was present in 12 Group I versus 4 Group II patients, whereas by transesophageal echocardiography, this sign was present in 15 Group I versus 4 Group II patients ($p = NS$ versus precordial echocardiography). Compared with precordial imaging, transesophageal imaging also permitted visualization of the ruptured chord in nine versus one of the patients in Group I ($p < 0.05$).

By transesophageal echocardiography in Group I, there was disagreement between the two observers about the presence of abnormal coaptation of mitral leaflets in one patient and about the presence of ruptured chordae in two

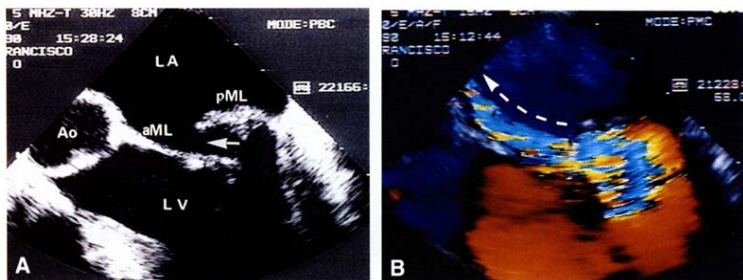


Figure 1 (top). Group I patient with a flail posterior mitral valve. **A.** Transesophageal echocardiographic view, showing abnormal leaflet coaptation in systole, displacement of the unsupported posterior mitral leaflet (pML) into the left atrium (LA) and formation of a "regurgitant channel" (arrow) between the mitral leaflets; aML = anterior mitral leaflet; Ao = aortic valve; LV = left ventricle. **B.** Doppler color flow mapping in the same view as in **A.** The eccentric mitral regurgitant jet (yellow and orange colors) originates on the ventricular side of the flail posterior mitral leaflet and moves peripherally in a clockwise direction (dashed arrow) through the regurgitant channel and over the atrial surface of the anterior mitral leaflet.

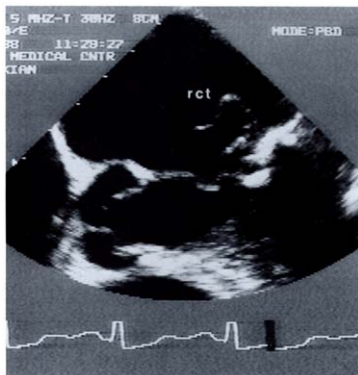


Figure 2 (center). Transesophageal cardiac four chamber view in a Group I patient with flail posterior mitral leaflet showing coiled ruptured mitral chordae tendineae (rct) in the left atrium during systole. The orientation is similar to that in Figures 1 and 3.

Figure 3 (bottom). Group II patient with mitral regurgitation due to ischemic heart disease. **A.** Transesophageal cardiac four chamber view. a and p = anterior and posterior leaflet, respectively; Ao = aortic valve; LA = left atrium; LV = left ventricle; mv = mitral valve. **B.** Doppler color flow mapping in comed-down view similar to that in **A.** The central mitral regurgitant jet (mr) moves posteriorly into the left atrium (arrow).

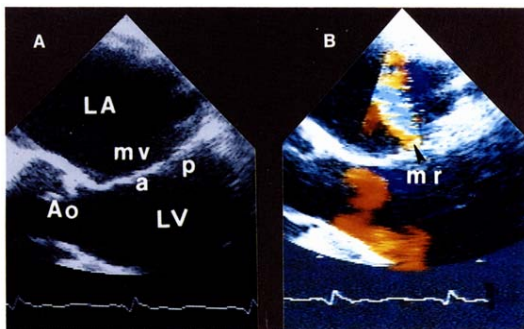


Table 2. Signs of Flail Mitral Valve: Precordial Versus Transesophageal Echocardiography

	Group I (n = 17)	Group II (n = 22)	p Value
Precordial echocardiography			
Imaging			
Abnormal mitral leaflet coaptation	12	4	<0.01
Ruptured chord	1	0	NS
Eccentric jet by Doppler color flow mapping	11	4	<0.01
Transesophageal echocardiography			
Imaging			
Abnormal mitral leaflet coaptation	15	4	<0.001
Ruptured chord	9*	0	<0.001
Eccentric jet by Doppler color flow mapping	17†	4	<0.001

*p < 0.01. †p < 0.05 vs analogous sign by precordial echocardiography.

patients. There was no disagreement about the lack of these findings in Group II patients. By precordial echocardiography, there was disagreement about the presence of the same signs in two and one, respectively, of the patients in Group I.

Pulsed wave Doppler ultrasound. By this technique, mitral regurgitation was found to be moderate or severe (2+ to 4+) in 12 Group I and 21 Group II patients; mild mitral regurgitation (1+) was found in 5 Group I versus 1 Group II patient (p = NS). Of these five Group I patients with 1+ regurgitation, four underwent cardiac catheterization with ventriculography; mitral regurgitation was graded as 3+ in two of these patients and 4+ in the other two patients.

Doppler Color Flow Mapping of Mitral Regurgitation

Jet shape and direction. All 17 Group I patients with a flail mitral valve leaflet due to ruptured chordae tendineae demonstrated an eccentric, peripherally directed mitral regurgitant jet that closely hugged the walls of the left atrium (Table 2). In comparison, only 4 (18%) of 22 Group II patients had an eccentric jet (p < 0.001). All 7 eccentric mitral regurgitation jets associated with a flail anterior leaflet were directed toward the posterolateral atrial wall (counterclockwise motion of the jet in the standard transesophageal four chamber view), whereas all 10 regurgitant jets associated with a flail posterior leaflet were directed toward the interatrial septum (clockwise motion of the jet in the standard transesophageal four chamber view, Fig. 1B). By precordial Doppler color flow mapping, 11 Group I and 4 Group II patients had an eccentric jet (p < 0.01).

Of the 22 Group II patients, 18 had central (Fig. 3) and 4 had eccentric mitral regurgitation by transesophageal echocardiography. Of the latter four patients, two had a jet that moved in a clockwise direction and two in a counterclockwise direction in the standard transesophageal four chamber view. Of the two patients with a clockwise jet, one had large bacterial vegetations on both mitral valve leaflets that directed the jet toward the interatrial septum; the other patient had ischemic

mitral valve disease. Of the two patients with a counterclockwise jet, one had rheumatic mitral valve disease with scarred and foreshortened chordae to the posterior mitral valve leaflet; the other patient had an abnormal scallop of the mitral valve that bridged the anterolateral commissure and prolapsed into the left atrium during systole.

Jet length and radius of curvature. By transesophageal echocardiography, the average mitral regurgitant color flow jet length was 8.5 ± 2.4 cm in Group I versus 4.5 ± 1.9 cm in Group II (p < 0.01), whereas radius of curvature averaged 2.8 ± 2.3 in Group I versus 7.5 ± 4.9 in Group II (p < 0.05). The ratio of jet length to radius of curvature averaged 0.5 ± 2.3 in Group I versus 0.7 ± 0.6 in Group II (p < 0.001). The minimal value for the ratio in Group I was 2.6, whereas the maximal value for the ratio in Group II was 2.1. Intraobserver variability for this ratio was 18%; interobserver variability was 31%. For classifying ratios > 0 or < 2.5 , there is complete agreement between observers.

Changes in Color Flow Imaging in Group I Patients After Mitral Valve Surgery

Mitral valve repair. Of the 10 Group I patients who underwent mitral valve repair, 8 had a technically successful repair. By intraoperative transesophageal echocardiography with Doppler color flow mapping in the eight patients with successful repair, the eccentric mitral regurgitant jet was either eliminated or converted into a trivial central jet after repair. The other two patients had significant residual mitral regurgitation and underwent mitral valve replacement several days after mitral valve repair. By intraoperative transesophageal echocardiography with Doppler color flow mapping, both of these patients still demonstrated eccentric mitral regurgitation after the initial valve repair.

Mitral valve replacement. By intraoperative transesophageal echocardiography with Doppler color flow mapping, all eight Group I patients who underwent mitral valve replacement had elimination of the eccentric mitral regurgitant jet after surgery. Seven of these patients had a tilting disc prosthesis inserted and were left with trivial or mild central prosthetic mitral regurgitation typical of the "seating puff" variety (24). The eighth patient underwent bioprosthetic mitral valve insertion and had no residual mitral regurgitation detected by transesophageal echocardiography.

Diagnostic value of echocardiographic signs for flail mitral valve. Of all the qualitative echocardiographic signs evaluated, the presence of eccentric mitral regurgitation by transesophageal Doppler color flow mapping was the most sensitive sign for flail mitral valve (100% sensitive, 82% specific) and was somewhat better than the same sign by precordial Doppler color flow mapping (65% sensitive, 82% specific). The specificity of this Doppler color flow sign for flail mitral valve could be improved utilizing quantitative information: a ratio of jet arc length to radius of curvature > 2.5 was 100% specific (as well as 100% sensitive).

Of the transesophageal echocardiographic imaging signs,

abnormal mitral leaflet coaptation was the most sensitive (88%) but least specific (82%). Conversely, visualization of the ruptured chord by transesophageal imaging was the most specific sign (100%), but was less sensitive (53%).

By precordial imaging, the presence of either one of the two imaging signs (abnormal mitral leaflet coaptation or ruptured chord) increased the sensitivity of precordial imaging to 76% but decreased specificity to 77%. Using the same criteria for transesophageal imaging resulted in a sensitivity of 100% and a specificity of 82% for the diagnosis of flail mitral valve.

Combining precordial echocardiography with precordial Doppler color flow mapping, the overall sensitivity and specificity for flail mitral valve were 82% and 77%, respectively. For transesophageal echocardiography combined with Doppler color flow mapping (qualitative signs only), these values were 100% and 82%, respectively.

Discussion

Transesophageal versus precordial echocardiography in the diagnosis of flail mitral valve. We found that transesophageal echocardiography had advantages over precordial echocardiography in the diagnosis of flail mitral valve due to ruptured chordae tendineae (Table 2). Transesophageal imaging showed a trend toward greater sensitivity and specificity than precordial imaging for the visualization of non-coapting mitral leaflets and ruptured chordae. In addition, transesophageal echocardiography was better than Doppler color flow mapping in the detection of an eccentric mitral regurgitant jet. Because transesophageal echocardiography provides higher resolution imaging of posterior cardiac structures (including the mitral valve, left atrium and mitral regurgitant color flow jets), these results are not surprising. The presence of eccentric mitral regurgitation by transesophageal Doppler color flow mapping was the most sensitive marker of a flail mitral valve, whereas the presence of a ruptured chord by transesophageal imaging was the most specific marker. Utilizing quantitative information on transesophageal echocardiography with Doppler color flow mapping, the ratio of jet arc length to radius of curvature may improve the ability to diagnose flail mitral valve leaflet. Unfortunately, the calculation of this ratio is somewhat tedious and difficult to reproduce. Prospective studies are indicated to further evaluate the usefulness of both qualitative and quantitative data.

Doppler color flow evaluation of the size and direction of mitral regurgitant jets. Previous investigators (13,14) have found that perioperative Doppler color flow mapping of mitral regurgitation during mitral valve reconstruction or coronary artery bypass grafting provides a reliable evaluation of the presence and severity of mitral regurgitation. Semiquantitative grading scales of the severity of mitral regurgitation by Doppler color flow mapping (13,14,25-27) have been developed using the area of the jet relative to that of the left atrium. These grading scales are based on the size

of the mitral regurgitant Doppler color flow jet and have been validated primarily in patients with a mitral regurgitant jet that penetrates into the central portion of the left atrium and does not closely adhere to the left atrial wall. In addition, these grading scales are influenced by numerous variables, including loading conditions, color frame rates, gain settings, color map algorithms and machine electronics (13,14,25,26).

Unlike the size of the mitral regurgitant color flow jet, the shape and direction of the jet are useful variables that may be relatively independent of other variables. In this study, we found that the presence of an eccentric color flow jet in mitral regurgitation was suggestive of a flail mitral valve. The ratio of arc length to radius of curvature may be helpful in quantifying the degree of eccentricity for the mitral regurgitant color flow jet. This ratio was significantly greater in Group I than in Group II patients; the lowest ratio in Group I was 2.6, whereas the highest ratio in Group II was 2.1. In addition, there was a correlation between elimination of the eccentric jet and successful mitral valve surgery. Because of the small number of patients evaluated in this study, further work is required in mitral valve repair.

Doppler color flow versus pulsed wave Doppler ultrasound. Doppler color flow mapping provides a near real-time flow map of the origin and direction of mitral regurgitation in the left atrium (27). Although this information can also be obtained by interrogating the entire left atrium by pulsed wave Doppler ultrasound (12), this method may be technically difficult or unreliable in patients with eccentric mitral regurgitation. For example, in this study, we underestimated the severity of mitral regurgitation by pulsed wave Doppler ultrasound relative to ventriculography in four patients with a flail mitral valve, probably as a result of inability to track the eccentric penetration of the mitral regurgitant jet around the periphery of the left atrium. Thus, the failure to detect the mitral regurgitant pulsed wave signal in the periphery of the left atrium created the false impression of mild mitral regurgitation in these patients.

Mechanism for eccentric mitral regurgitant color flow jet. In patients with a flail mitral valve, we believe that the eccentric shape of the mitral regurgitant jet by Doppler color flow mapping is caused by abnormal mitral leaflet coaptation. Because of ruptured chordae tendineae, the affected mitral leaflet is inadequately tethered during systole. The unsupported portion of the leaflet thus moves into the left atrium and forms a channel that directs regurgitant flow toward the opposite leaflet (Fig. 1). Once this channel is formed, the eccentric mitral regurgitant flow can move over the atrial surface of the opposite mitral leaflet, onto the adjacent left atrial wall and around the left atrium in a circular motion.

An eccentric color flow mitral regurgitant jet was not limited to Group I patients. Of the four Group II patients (without a flail mitral valve) who demonstrated an eccentric Doppler color flow jet, three had abnormalities in mitral leaflet coaptation that permitted a regurgitant channel to be formed. One patient had bacterial endocarditis with bulky

vegetations on both mitral valve leaflets, the second patient had rheumatic mitral valve disease with scarred and foreshortened chordae to the posterior mitral valve leaflet and the third patient had an abnormal mitral valve scallop that bridged the anterolateral commissure and prolapsed into the left atrium during systole. Despite the qualitative impression that these four Group II patients had an eccentric mitral regurgitation jet, the ratio of jet arc length to radius of curvature was still <2.1 in these patients. Thus, in questionable cases, calculation of this ratio may help exclude the diagnosis of flail mitral valve due to ruptured chordae tendineae.

Limitations of transesophageal echocardiography. Transesophageal echocardiography cannot be performed in all patients. Those who have esophageal varices, strictures, diverticula, prior esophageal surgery or active upper gastrointestinal bleeding should be precluded from study. In addition, in occasional patients, it may be technically difficult to pass the probe into the esophagus.

Furthermore, there are problems involved with the semi-quantitative evaluation of mitral regurgitation by transesophageal echocardiography with Doppler color flow mapping. Cardiac loading conditions, heart rate and equipment variables may affect jet size. In patients with a dilated left atrium, the entire atrium may not be imaged on a single screen. The dome of the left atrium may be especially difficult to image in certain patients. Also, eccentric jets may occasionally not be well imaged in the standard viewing planes and require "off-axis" views.

Differentiation of anterior and posterior flail leaflets by Doppler color flow mapping. By the Doppler color flow patterns we described, anterior and posterior flail mitral valve leaflets could be readily distinguished on the basis of the direction of flow of the regurgitant jet. In the standard transesophageal four chamber view, mitral regurgitation associated with a flail anterior leaflet moved in a counter-clockwise direction around the left atrium in the standard transesophageal four chamber view, whereas regurgitation associated with a flail posterior leaflet moved in clockwise direction.

Cardiac surgery without catheterization. In 6 of the 17 Group I patients, mitral valve surgery was performed without preoperative cardiac catheterization. This suggests that in selected patients with a flail mitral valve (that is, those with a low risk for coronary artery disease or other cardiac lesions), transesophageal echocardiography may be adequate to characterize the cardiac disease before mitral valve surgery.

Comparison with previous studies. The results of this study support previous findings (7,28) that transesophageal echocardiography may have advantages over precordial echocardiography in the diagnosis of flail mitral valve. We confirmed the mitral valve disease at surgery in all patients and did not exclude patients with rheumatic disease. By pulsed wave Doppler ultrasound, markedly disturbed antegrade flow in the left atrium has been described in patients with a flail mitral valve (29) and angled mitral

regurgitant jets have been previously noted in patients with mitral valve prolapse and flail mitral valve (20,31). Eccentric and turbulent mitral regurgitation jets by precordial Doppler color flow mapping have also been recently reported in patients with a flail mitral valve (32).

Conclusion. We found that transesophageal imaging and Doppler color flow mapping of mitral regurgitation were complementary to precordial echocardiography in the diagnosis and localization of a flail mitral valve due to ruptured chordae tendineae. The direction of the eccentric jet in the left atrium helped distinguish anterior and posterior flail leaflets. An elevated value for the ratio of jet arc length to the radius of curvature also correlated with the presence of a flail mitral valve leaflet.

References

- Sweeten T, Selzer A, Kanagaki M, Cohn K. Echocardiographic diagnosis of mitral regurgitation due to ruptured chordae tendineae. *Circulation* 1972;46:580-6.
- Mintz GS, Kotler MN, Segal BL, Parry WR. Two-dimensional echocardiographic recognition of ruptured chordae tendineae. *Circulation* 1978; 57:244-50.
- Child JS, Skorton DJ, Taylor RD, et al. M-mode and cross-sectional echocardiographic features of flail posterior mitral leaflets. *Am J Cardiol* 1979;44:1335-50.
- Mintz GS, Kotler MN, Parry WR, Segal BL. Statistical comparison of M-mode and two-dimensional echocardiographic diagnosis of flail mitral leaflets. *Am J Cardiol* 1980;45:253-9.
- Mintz GS, Kotler MN, Segal BL, Parry WR. Two-dimensional echocardiographic recognition of ruptured chordae tendineae. *Circulation* 1978; 57:244-50.
- Bollester M, Finkle R, Presbitero P, Yacoub M, Richards A, McDonald L. Cross-sectional echocardiographic features of ruptured chordae tendineae. *Eur Heart J* 1983;4:795-802.
- Schlüter M, Kremer P, Hanrath P. Transesophageal 2-D echocardiographic features of flail mitral leaflet due to ruptured chordae tendineae. *Am Heart J* 1984;108:509-10.
- Galloway AC, Colvin SB, Baumann FG, Hartz S, Spencer FC. Current concepts of mitral valve reconstruction for mitral insufficiency. *Circulation* 1988;78:1047-58.
- Bushour JT, Andrade GE, Hanna ES, Mason DT. Repetitive operations for mitral valve incompetence: an emerging treatment of choice. *Am Heart J* 1987;113:1999-2006.
- Carpentier A, Chauvaud S, Fabiani JN, et al. Reconstructive surgery of mitral valve incompetence: ten year appraisal. *J Thorac Cardiovasc Surg* 1980;79:338-48.
- Oliviera DBG, Kawkins KD, Kay FH, Powell M. Chordal rupture: comparison between repair and valve replacement. *Br Heart J* 1983;50: 318-24.
- Abassi AS, Allen MW, DeCristoforo D, Ungar I. Detection and estimation of the degree of mitral regurgitation by range-gated pulsed Doppler echocardiography. *Circulation* 1980;61:143-7.
- Czer LSC, Maurer G, Bolger AP, et al. Intraoperative evaluation of mitral regurgitation by Doppler color flow mapping. *Circulation* 1987;76(suppl III):II-108-16.
- Maurer G, Czer LSC, Choux A, et al. Intraoperative Doppler color flow mapping for assessment of valve repair for mitral regurgitation. *Am J Cardiol* 1987;60:333-7.
- Schlüter M, Maurer G, Ritter SB, et al. American Society of Echocardiography Committee on Special Procedures: statement on transesophageal echocardiography. *J Am Soc Echo* 1989;2:354-7.
- Schlüter M, Hinrichs A, Thiel W, et al. Transesophageal two-dimensional echocardiography: comparison of ultrasonic and anatomic sections. *Am J Cardiol* 1984;53:1173-8.

17. Sellers RD, Levy MJ, Amplatz K, Lillehei CW. Left retrograde cardiography in acquired cardiac disease. Technic, indication and interpretations in 700 cases. *Am J Cardiol* 1964;14:437-47.
18. Waller BF, Morrow AG, Maron BJ, et al. Etiology of clinically isolated, severe, chronic pure mitral regurgitation: analysis of 97 patients over 30 years of age having mitral valve replacement. *Am Heart J* 1982;104:276-88.
19. Olson LJ, Subramanian R, Ackerman DM, Orszulak TA, Edwards WD. Surgical pathology of the mitral valve: a study of 712 cases spanning 21 years. *Mayo Clin Proc* 1987;62:22-4.
20. Czer LSC, Gray RJ, DeRobertis MA, et al. Mitral valve replacement: impact of coronary artery disease and determinants of prognosis after revascularization. *Circulation* 1984;70(suppl 1):1-198-207.
21. Burgess HJ, Clark R, Kamigaki M, Cohn K. Echocardiographic findings in different types of mitral regurgitation. *Circulation* 1973;48:97-106.
22. Umeda T, Kawako K, Machi K. M-mode and cross-sectional echocardiographic evaluation of rheumatic mitral valve disease. *Jpn Circ J* 1979;43:297-304.
23. Morcerf F, Salcedo EE, Siegel W. Echocardiographic determination of the etiology of severe mitral regurgitation. *Cleve Clin Quart* 1976;43:163-74.
24. Tamis MA, Gussenhoven EJ, Cahalan MK, et al. Transesophageal Doppler color flow imaging in the detection of native and Bjork-Shiley mitral valve regurgitation. *J Am Coll Cardiol* 1989;13:95-9.
25. Miyatake K, Okamoto M, Kinoshita N, et al. Clinical applications of a new real-time two-dimensional Doppler flow imaging system. *Am J Cardiol* 1984;54:857-68.
26. Helmcke F, Nanda NC, Hwang MC, et al. Color Doppler assessment of mitral regurgitation using orthogonal planes. *Circulation* 1987;75:175-82.
27. Perry GJ, Nanda NC. Color Doppler echocardiography. *Int J Card Imaging* 1989;3:183-91.
28. Hozumi T, Yoshikawa J, Yoshida K, Yamaura Y, Akasaka T, Shizudo M. Direct visualization of ruptured chordae tendineae by transesophageal echocardiography. *J Am Coll Cardiol* 1990;16:1315-9.
29. Habbab MA, Haft JJ. Characteristic pulsed Doppler findings in patients with flail mitral valve. *Chest* 1987;91:571-1.
30. Hatle L, Angelsen B. Pulsed and continuous wave Doppler in diagnosis and assessment of various heart lesions. In: *Doppler Ultrasound in Cardiology: Physical Principles and Clinical Applications*, ed 2. Philadelphia: Lea & Febiger, 1985:176-88.
31. Miyatake K, Nimura Y, Sakakibara H, et al. Localization and direction of mitral regurgitant flow in mitral orifice studied with combined use of ultrasonic pulsed Doppler technique and two-dimensional echocardiography. *Br Heart J* 1982;48:449-59.
32. Forstner AC, Sr Vranic J, Mrosov D, Labovitz AJ. Color Doppler echocardiographic evaluation of patients with a flail mitral leaflet. *J Am Coll Cardiol* 1990;16:232-9.