Detection and Estimation of the Degree of Mitral Regurgitation by Range-gated Pulsed Doppler Echocardiography

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SUMMARY Sensitivity and specificity of detection of mitral regurgitation was assessed by range-gated Doppler echocardiography. The degree of mitral regurgitation was also estimated by the depth and width of the regurgitant jet detected with Doppler and compared with that assessed by left ventriculography. Of 47 patients with an adequate Doppler study, 24 had no mitral regurgitation by ventriculography. All but one were also negative for mitral regurgitation by Doppler, for a specificity of 96%. Of 23 cases with mitral regurgitation documented by ventriculography, Doppler detected mitral regurgitation in 21, for a sensitivity of 92%. Two cases with mitral regurgitation undiagnosed by Doppler had mild mitral regurgitation due to papillary muscle dysfunction. All cases with rheumatic mitral regurgitation were detected. The degree of mitral regurgitation estimated with Doppler had a high correlation with that determined by ventriculography ($r = 0.88, p < 0.01$).

CONVENTIONAL M-MODE echocardiography has limited value in the diagnosis of mitral regurgitation, because often no associated structural abnormality of the mitral valve can be detected. Also, when the mitral valve echo is abnormal, as in mitral valve prolapse or calcific mitral annulus, mitral insufficiency may or may not be present.

A range-gated pulsed Doppler has been recently developed that can identify normal or abnormal flow patterns within intracardiac locations and thus detect valvular regurgitation.$^{1-3}$ In the present study, we analyzed the sensitivity and specificity of Doppler echocardiography in detecting mitral regurgitation. We also attempted to estimate the degree of mitral regurgitation using this technique.

Methods

The details of the principles and general application of Doppler echocardiography have been recently published.$^{4,5}$ In summary, Doppler ultrasound instruments are based on Doppler shift or Doppler effect which indicates that sound frequency reflected from moving surfaces such as blood cells within the heart or blood vessels is altered in proportion to the velocity of their movement. Reflected sound waves from the blood cells are analyzed using a special Doppler shift-detector system. Range gating allows the signals to be accepted from a teardrop-shaped $2 \times 4$-mm sample...
volume that can be positioned within the heart chambers and great vessels.

In this study, a commercially available echo Doppler system was used.* A 3-MHz piezoelectric transducer with a ½-inch diameter and 5-cm focus was placed over the chest wall, slightly lower than conventional positions. The M-mode signal was first obtained to identify the mitral valve. The sample volume was then placed immediately posterior to the mitral valve within the left atrium. The returning signals were recorded both on the stereophonic audio and graphic display systems. The latter was printed on a strip chart recorder (Honeywell #1856). A circuit built into the Doppler system analyzes the flow and creates a time interval histogram.† ‡ A normal laminar flow produces a smooth, musical sound that has a narrowly clustered dot pattern (narrow band) on the histogram. An abnormal or disturbed flow produces a harsh, multiple-frequency sound that has a widely dispersed dot pattern (wide band).

To estimate the degree of mitral regurgitation, the beam was first directed to obtain the maximum motion of the mitral valve, and the sample volume was placed posterior to this area. The beam was then directed to record the aortic root and the left atrium while the sample volume was moved back and forth within the left atrium.

Mitral regurgitation was estimated on the basis of the location and area of distribution of the abnormal systolic flow detected within the left atrium. Thus, there was no mitral regurgitation if no abnormal systolic flow was detected; 1+ mitral regurgitation if the systolic flow was localized immediately posterior to the mitral valve; 2+ mitral regurgitation when the abnormal systolic flow was recorded at a wider area posterior to the mitral valve, but was absent as the beam was directed toward the aortic root and the mitral valve disappeared from view; 3+ mitral regurgitation when the area of the abnormal flow was present well posterior to the mitral valve reaching the anterior half of the atrial cavity; 4+ mitral regurgitation when the flow was present diffusely all over the left atrium, and could be followed up to the mitral valve.

Mitral regurgitation was also estimated by left ventriculography as 0 (none); 1+ (mild); 2+ (moderate); 3+ (moderately severe); and 4+ (severe), depending on the degree of opacification of the left atrium, the apparent size of the left atrium and the number of cardiac cycles required for maximal opacification. Doppler echocardiography was performed and interpreted by two of the investigators, who agreed on the degree of mitral regurgitation without knowing the clinical and angiographic findings. The left ventriculograms were interpreted by two other investigators, again without knowing the patient's history or Doppler findings. Doppler studies were completed within 48 hours of cardiac catheterization.

Case Selection

Fifty consecutive patients undergoing cardiac catheterization and left ventriculography for suspected ischemic or rheumatic heart disease also had Doppler echocardiography. The Doppler studies were not adequate in three patients, who were excluded because of poor penetration of sound through the chest. The remaining 47 patients are the subjects of this study. Their mean age was 45 years (range 20–76 years). Patients with congenital heart disease were not included.

Results

In 24 cases without mitral regurgitation by left ventriculography, 23 had no mitral regurgitation by Doppler (table 1). In these patients, a laminar or smooth, musical blood flow signal was audible only during ventricular diastole. This signal was located posterior to the mitral valve and within the left atrium. The flow occurred with mitral opening and again during atrial systole (fig. 1). A narrow dot pattern is clearly seen in two peaks during ventricular diastole.

During ventricular systole, no flow signal was detected in the left atrium posterior to the mitral valve except in one patient who had an increased left atrial flow due to anemia and was falsely diagnosed as having mitral regurgitation. Thus, Doppler was 96% specific in excluding the diagnosis of mitral regurgitation. The other 23 patients had mitral regurgitation by left ventriculography (table 1). In 21 of these patients, a distinctly abnormal systolic flow pattern was detected posterior to the mitral valve and within the left atrium (fig. 2). A wide-band pattern of signal during systole is clearly seen on the strip chart. The diastolic flow is also enhanced, as evidenced by the increased duration of signal during diastole. Two cases of mitral insufficiency were missed with Doppler. Thus, Doppler was 92% sensitive in detecting mitral regurgitation.

Twenty-three patients with mitral regurgitation by ventriculography were further categorized into two subsets – eight rheumatic and 15 nonrheumatic. All cases with rheumatic mitral regurgitation were detected with Doppler (100% sensitivity). Two cases with nonrheumatic mitral insufficiency were missed (88% sensitivity). These two cases had mild mitral regurgitation due to ischemic heart disease and papillary muscle dysfunction. The degree of mitral

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* indicates patients with mitral regurgitation; - indicates patients without mitral regurgitation.

*Advanced Technology Laboratory, Bellevue, Washington.
regurgitation estimated by Doppler was compared to that assessed by left ventriculography (fig. 3). A high correlation was noted between the two methods ($r = 0.88, p < 0.01$ using Pearson's method).

Discussion

Doppler echocardiography may be compared to intracardiac phonocardiography for detection and localization of abnormal intracardiac blood flow.

Figure 1. Normal mitral valve flow. (top) A compressed motion scan of the mitral valve (MV) with the sample volume (SV) location indicated by a straight line. (bottom) Flow display. The diastolic mitral valve flow has two peaks (small arrows) corresponding to the initial openings and the atrial wave of the mitral valve. Note the absence of flow signal during ventricular systole, which begins at the time of mitral valve closure (C).

Figure 2. Mitral valve flow in mitral regurgitation. The systolic flow signal is shown between the two arrows. In addition, the diastolic flow signal appears to be more prominent. This record was taken at a faster paper speed than figure 1.
However, the major advantage of Doppler is that it is noninvasive. Another advantage is the capability of estimating the severity of regurgitant flow, which is not possible by any other noninvasive technique.

Doppler echocardiography is still in its developmental phase, and certain problems must be pointed out. The sample volume is fixed and small, 2 X 4 mm, and therefore it is possible to miss mild mitral regurgitation, especially if the leak occurred at a localized area of the mitral valve or if the systolic jet was directed to a location in the left atrium where the sample volume could not be placed. However, it seems that the regurgitation jet in rheumatic mitral insufficiency was easily detected without any false-negative cases. Two cases with mild mitral regurgitation due to papillary muscle dysfunction were missed. These patients had mild mitral regurgitation and were in heart failure. Therefore, a low cardiac output probably resulted in a small regurgitant flow that was not detected with Doppler. However, even in these cases it may be possible to register an audible signal if the beam is positioned immediately posterior to the mitral valve and this area is explored carefully. With more experience, we have been able to detect a small, localized area of mitral regurgitation.

An increased left atrial flow may occur in high-output states. One patient with anemia who had a systolic murmur and was thought to have mitral regurgitation by Doppler did not have mitral regurgitation by left ventriculography. This patient did not have a typical disturbed systolic flow of mitral regurgitation but had an almost continuous flow signal in the left atrium at the level where the aorta rather than the mitral valve was seen anteriorly. The flow signals could not be traced up to the mitral valve, which should have helped to exclude mitral regurgitation. The abnormal left atrial flow in this case was probably due to increased pulmonary venous return.

Our results for the detection of mitral regurgitation by pulsed Doppler are similar to those reported recently by Johnson et al.\textsuperscript{2} and Stevenson et al.\textsuperscript{3} However, the degree of mitral regurgitation was not estimated in their studies.

Assessment of mitral regurgitation has been attempted by a continuous-wave Doppler\textsuperscript{1} using aortic arch flow velocity. However, continuous-wave Doppler cannot be range gated, so the cumulative effect of sound signals from adjoining structures may be difficult to interpret. The more direct method of pulsed Doppler described in our study is preferable.

Doppler estimation of degree of mitral regurgitation was remarkably consistent and correlated well with that determined by ventriculography. In the assessment of mitral regurgitation by either method a similar general principle was used. It was the distribution of regurgitant dye noted during ventriculography compared with the distribution of regurgitant flow detected in the left atrium by Doppler.

We anticipated that a high-pressure systolic jet in patients with normal-to-anal flow might produce a more intense flow signal, although the mitral regurgitation may not be significant. However, this did not pose a problem. Although the flow signal was increased in these patients, the jet did not spread widely within the left atrium unless the mitral regurgitation was significant. Similarly, patients with low cardiac output but significant mitral regurgitation had less intense flow signals, but the signal was widespread rather than localized. In severe mitral regurgitation, there was also an increase in diastolic flow, causing a to-and-fro type of flow pattern within the left atrium. This type of flow signal helped to indicate that the mitral regurgitation was significant, even when the signal did not reach the posterior half of a very dilated left atrium.

There was some overlap between 2+ to 3+ mitral regurgitation. However, if one were to classify mitral regurgitation by Doppler as mild, moderate and severe, a better separation of abnormal systolic flow patterns was recognized in each case. Not all the Doppler and angiographic studies were performed at the same time, but were completed within 48 hours of each other. This may, to some extent, explain the difference between the degree of mitral insufficiency assessed by either of the techniques. Further, although presently considered the "gold standard," ventriculography has significant inherent problems in determining the degree of valvar insufficiency.\textsuperscript{10, 11}

The present method of echo Doppler graphic display\textsuperscript{4, 6, 8} has technical limitations that makes it less sensitive and more vulnerable to extra noise interferences than the audible detection system. In some cases in our study, an adequate record of mitral regurgitation on a strip chart was difficult to obtain, although it was clearly audible. Therefore, the audio signal was preferentially used to categorize our patients. We hope that better methods of graphic recording and interpretations of sounds will soon be available. Even in its present form, however, Doppler echocardiography was found to be highly sensitive and specific for the detection of mitral regurgitation. In
addition, the degree of mitral regurgitation as estimated by pulsed Doppler had a high correlation with that determined by ventriculography.

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