Color Doppler assessment of mitral regurgitation with orthogonal planes

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ABSTRACT  We evaluated 147 patients with adequate color Doppler and angiographic studies for mitral regurgitation. Sixty-five patients had no mitral regurgitation by both color Doppler and angiography and 82 patients had mitral regurgitation by both techniques. Thus the sensitivity and specificity of color Doppler for the detection of mitral regurgitation was 100%. Three two-dimensional echocardiographic planes (parasternal long and short axis, apical four-chamber view) were used to analyze variables of the mitral regurgitant jet signals in the left atrium. The best correlation with angiography was obtained when the regurgitant jet area (RJA) (maximum or average from three planes) expressed as a percentage of the left atrial area (LAA) obtained in the same plane as the maximum regurgitant area was considered. The maximum RJA/LAA was under 20% in 34 of 36 patients with angiographic grade I mitral regurgitation, between 20% and 40% in 17 of 18 patients with grade II mitral regurgitation, and over 40% in 26 of 28 patients with severe mitral regurgitation. Maximum RJA/LAA also correlated with angiographic regurgitant fractions (r = .78) obtained in 21 of 40 patients in normal sinus rhythm and with no evidence of associated aortic regurgitation. Other variables of the regurgitant jet such as maximal linear and transverse dimensions, maximal area, or maximal area expressed as a percentage of the LAA in one or two planes correlated less well with angiography. Color Doppler is a useful noninvasive technique that is not only highly sensitive and specific in the identification of mitral regurgitation but also provides accurate estimation of its severity.


THE RECENT DEVELOPMENT of color Doppler flow imaging, which superimposes color-coded flow patterns on real-time two-dimensional images, has made it possible to map abnormal flow patterns such as those seen in patients with valvular regurgitation. Two preliminary studies1,2 have shown its value in the detection and quantitative assessment of mitral regurgitation. However, in both studies color Doppler failed to accurately predict the severity of mitral regurgitation in a significant number of patients. In the present study, we examined the usefulness of color Doppler in the assessment of mitral regurgitation in a comprehensive manner evaluating several criteria and utilizing multiple echocardiographic views.

Materials and methods

The original study consisted of 160 patients. However, 13 were excluded, eight because of poor acoustic window and inadequate echocardiographic images of the left atrium and five because of the presence of multiple premature ventricular contractions at the time of angiography, making the quantitation of mitral regurgitation impossible. Thus a total of 147 patients who had adequate color Doppler and angiographic examinations form the basis of this study. There were 79 men and 68 women, ranging in age from 17 to 84 years (mean 56). Eighty-two patients had mitral regurgitation by angiography, and the remaining 65 demonstrated normal mitral valvular function. The etiology of mitral regurgitation was ischemic heart disease in 34 rheumatic heart disease in 24, congestive cardiomyopathy in 13, and mitral valve prolapse in 11. Thirty-one of the 82 patients with mitral regurgitation were in atrial fibrillation and the remaining were in normal sinus rhythm. None of the patients without mitral regurgitation were in atrial fibrillation.

Concomitant aortic valve disease was present in 22 patients (aortic stenosis in one, aortic insufficiency in 18, and aortic stenosis and insufficiency in three).

Cardiac catheterization and angiography. Biplane cineangiography was performed in the standard manner in all patients, and mitral regurgitation was graded according to the criteria of Nagle et al.4: grade I or mild (n = 36), grade II or moderate (n
= 18), and grade III or severe (n = 28). The mean interval between angiography and color Doppler examination was 2.5 days (range 0 to 17). Mitral regurgitant fractions could be calculated in 21 patients who underwent both left and right heart catheterization and who were in normal sinus rhythm with no evidence for other associated valvar regurgitant lesions or intracardiac shunting. Forward cardiac output was measured by the Fick technique in 13 patients and by thermolution with Swan-Ganz catheterization in eight patients. Left ventricular end-diastolic and end-systolic volumes were obtained by means of biplane angiography with the area-length method of Dodge et al. 3 The regression equation of Wynne et al. 4 was used to correct for overestimation. Regurgitant fractions were calculated as differences between angiographic and hemodynamic cardiac outputs divided by angiographic outputs and expressed as percent. 7

Color Doppler. Color Doppler examinations were performed with a commercially available system (Irex-Aloka 880) and a 2.5 or 3.5 MHz transducer. Pulse repetition frequencies of 4, 6, or 8 Hz were available. A frequency of 4 Hz was routinely used, which allowed measurement of velocities up to 60 cm/sec. A higher pulse repetition frequency could sometimes be used from the parasternal window because the mitral regurgitation jet in this view was relatively close to the chest wall. This allowed measurement of higher velocities without aliasing. Doppler color gain was optimized as described previously. 2 Briefly, the gain was first turned down completely and then increased very gradually until the static background noise just appeared. Parasternal long-axis (LX), parasternal short-axis (SX), and apical four-chamber (A4C) views were obtained in all patients. Mitral regurgitation was considered to be present if blue, green, or mosaic signals were seen originating from the mitral valve and spreading into the left atrium during systole. 1, 2, 8, 9

Video tapes were carefully analyzed frame-by-frame to compute the maximum linear and transverse dimensions as well as the maximum area of the regurgitant jet signals (RJA) in all three planes (figure 1). Depending on the spatial orientation of the planes examined, the dimensions of the mitral regurgitant jet (RJ) were categorized as length, height, and width  2, 8, 9 (figure 1). By means of a software program already incorporated in the equipment, the outline of the RJA was traced with a joystick and the area was measured by computerized planimetry. The plane with the maximum linear or transverse dimension was not necessarily the same plane in which the maximum RJ was noted. The left atrial area (LAA) was also measured by computerized planimetry in the same frame in which the maximum RJ was seen (figures 1 and 2).

Measurements of the RJ, which were compared with angiographic grading, were as follows:

1. Maximum dimensions (L = length, W = width, H = height), RJA, and RJA/LAA in each of the three planes (LX, SX, and A4C).

2. Maximum dimensions, maximum and average RJA, and RJA/LAA taking into consideration two planes together (LX + SX, LX + A4C, SX + A4C, LX/SX, LX/A4C, SX/A4C).

3. Maximum and average RJA and RJA/LAA taking into consideration all three planes. The average of two maximum RJA and RJA/LAA as well as the average of all three dimensions were also correlated.

To evaluate interobserver variability, color Doppler measurements in one of the planes (LX) were obtained in 40 randomly selected cases by two independent observers who had no knowledge of angiographic data. Agreement was uniformly close throughout the range of RJA/LAA% from the LX with a correlation factor of .99 (figure 3). All angiograms were evaluated by a cardiac radiologist in a blinded fashion. Analysis of 40 randomly selected angiograms also showed excellent correlation in the findings of the two cardiac radiologists. There was a discrepancy in three cases: two grade II were classified as grade III and one grade I was judged to be grade II by a second radiologist. These three cases were reviewed by both radiologists and a consensus was reached.

FIGURE 1. Diagramatic representation of the variables assessed by color Doppler. Top left, Apical four-chamber view; top right, parasternal long-axis view. Bottom left, Apical four-chamber view (the technique for measurement of the RJA and the LAA is shown); bottom right, parasternal short-axis view. RV = right ventricle; TV = tricuspid valve; RA = right atrium; LV = left ventricle; MV = mitral valve; L = maximal length of the regurgitant jet; W = maximal width of the regurgitant jet; H = maximum height of the regurgitant jet; LA = left atrium; Ao = aorta; AV = aortic valve. The dotted area represents the abnormal color Doppler signals produced by mitral regurgitation.
FIGURE 3. Interobserver variation. The maximum color Doppler RJA/LAA obtained by one observer in the parasternal long-axis view in 40 randomly selected cases are compared with the findings from a second independent observer. Note the excellent correlation.

The color Doppler findings were also compared with mitral regurgitant fractions obtained by cardiac catheterization and angiography in 21 of 40 patients who were in normal sinus rhythm with no evidence of aortic regurgitation or intracardiac shunting. All measurements of regurgitant fraction were performed by an independent observer who had no knowledge of color Doppler findings.

In the statistical analysis of the results, the significance of the differences between the mean values was assessed by the Student test (t and p values).

Results

Color Doppler flow imaging detected mitral regurgitation in all patients proved to have this lesion, whereas all patients without mitral regurgitation by angiography also had negative color Doppler findings. Thus both the sensitivity and specificity of color Doppler for detection of mitral regurgitation was 100% in patients in whom adequate color Doppler and angiographic studies were obtained.

Neither the dimensions (an example of which is shown in figure 4) nor area of the RJ assessed in any single plane correlated well with angiographic severity of mitral regurgitation. The correlation did not improve when the RJA was expressed as a percentage of the LAA calculated in the same frame. Interestingly, when two or three orthogonal planes were taken into account, both the maximal and the average dimensions as well as both the average and maximal RJA showed some correlation with angiographic grading, but significant overlap was noted, making it difficult to use these indexes to predict the severity of mitral regurgitation reliably (examples shown in figures 5 and 6). An improvement in correlation of the RJA indexes with angiographic grading was noted when the LAA was also taken into account, although overlap was still present when average or maximal RJA/LAA% from only two orthogonal planes was used (figures 7 and 8).

Excellent angiographic correlation was achieved with the average of three maximum RJA/LAA ratios (from three planes), the maximum RJA/LAA ratio taking into consideration all the three planes, and the average of the two highest RJA/LAA ratios (figures 9 and 10). Thirty-four of 36 patients with a maximum RJA/LAA% under 20% had grade I mitral regurgitation (predictive value 100%, sensitivity 94%, specificity 100%); 17 of 18 patients with an RJA/LAA% between 20% and 40% had grade II mitral regurgitation (predictive value 85%, sensitivity 94%, specificity 95%); 26 of 28 patients with an RJA/LAA% over 40% had severe mitral regurgitation (predictive value 93%, sensitivity 93%, specificity 96%) (figure 10). The maximum RJA/LAA% was found in the LX plane in 36

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FIGURE 4. Maximal length of color Doppler mitral regurgitation signals obtained from the apical four-chamber plane compared with angiographic grading. AF = atrial fibrillation; NSR = normal sinus rhythm.
Discussion

The severity of mitral regurgitation has generally been graded with conventional pulsed Doppler echocardiography by the depth the jet extends into the left atrium, but this is a blind technique that has been known to both underestimate and overestimate severity.\textsuperscript{12} Therefore, there is a need for a noninvasive technique that would provide more accurate characterization of the severity of mitral regurgitation.

We were also able to correlate the color Doppler findings with mitral regurgitant fractions obtained by cardiac catheterization and angiography in 21 of 40 patients who were in normal sinus rhythm with no evidence of aortic regurgitation or intracardiac shunting. The correlation coefficient was .78 for maximal RJA/LAA\% and .74 for maximum RJA, both obtained from analysis of the three planes studied (figures 12 and 13).
The recently developed technique of color Doppler flow imaging superimposes flow patterns on two-dimensional images in real time.\textsuperscript{1,8,9} The ability to readily scan the left atrium for abnormal flow signals such as those seen with mitral regurgitation makes color Doppler examination more comprehensive and less tedious and time consuming than conventional pulsed Doppler. A few reports have appeared in the literature demonstrating the utility of this technique not only in diagnosing mitral regurgitation but also in estimating its severity.\textsuperscript{1,2} However, in one study this technique failed to identify a significant number of patients with mild mitral regurgitation.\textsuperscript{2} In this study, grading of mitral regurgitation was also attempted by noting the maximum depth of the mitral regurgitation signals in the left atrium in a single two-dimensional plane. Although fairly good correlations were obtained with angiographic grading, significant overlap was noted, which considerably diminished its clinical usefulness.

One explanation may be that the color Doppler approach used by these investigators is practically identical to that used in conventional Doppler evaluation of the severity of mitral regurgitation. The single measurement of the maximum depth of the RJ used in those studies ignores other dimensions as well as the area of the RJ. Also, no attempt was made to study the RJ in orthogonal two-dimensional echocardiographic planes.

In our study there was some correlation between the length, width, and height of the RJ signals and the angiographic grading when examined in only one plane. This correlation improved to some extent when two or more orthogonal planes were taken into account, but significant overlap still existed, which considerably diminished its clinical usefulness. Examination in three orthogonal planes provides some estimate of the three-dimensional size of the RJ signals and would thus be expected to be superior to viewing them in only one or two planes. For example, a thin but long
and wide RJ may appear large when evaluated in only one two-dimensional plane that measures its length and width but not its thickness. This would give an erroneous impression of its size, resulting in overestimation of severity of mitral regurgitation. Such an error could be avoided if the RJ was also viewed in an orthogonal plane, which would delineate its third dimension and result in a more comprehensive assessment of its size.

Although calculation of the linear measurements of the RJ in all three orthogonal views resulted in a better correlation with the angiography grading of mitral regurgitation, we found estimation of the RJ area more accurate. The RJA also correlated better with angiographic grading when two or three planes were considered as compared with its assessment in any single plane. However, the best correlations with angiography were obtained when the RJA was expressed as a percentage of the area of the left atrium occupied by it. The improvement in correlation of color Doppler findings with angiography when the left atrial size is also taken into account probably reflects the dependence of severity on both size and compliance of the left atrium. A small left atrium would be expected to provide more resistance to systolic regurgitant filling than a large, baggy atrium that has lost its compliance. As a matter of fact, we found a significant correlation between RJA and RJA, especially with moderate and severe mitral regurgitation (figure 14). It is also important to realize that the abnormal Doppler signals seen in the left atria of patients with mitral regurgitation result not only from the high-velocity, high-energy reversed regurgitant flow but also from the disturbance it creates in the body of blood already present in the atrium, which is passively filling from pulmonary veins during systole.

**Limitations.** It should be emphasized that color Doppler flow mapping cannot be used satisfactorily to detect the presence and assess the severity of mitral regurgitation in patients with small acoustic windows in whom adequate quality two-dimensional echocardiographic studies cannot be obtained. This occurred in eight of 160 (5%) patients in this study.

**FIGURE 9.** Average RJA/LAA% obtained from analysis of all three two-dimensional echocardiographic planes compared with angiography. Abbreviations as in figure 4.

**FIGURE 10.** Maximum RJA/LAA% obtained from analysis of all three two-dimensional echocardiographic planes compared with angiography (all 82 patients). Abbreviations as in figure 4.
Figure 11. Maximum RJA/LAA% obtained from analysis of all three two-dimensional echocardiographic planes compared with angiography (first 30 patients studied). Abbreviations as in figure 4.

On the other hand, if a satisfactory study can be performed, improper gain settings may lead to erroneous quantitation of the amount of mitral regurgitation. In our experience, small variations in gain do not produce any changes in the size of the RJA. However, excessively low gain would result in underestimation of regurgitation because of elimination of lower velocity signals. An excessively high gain would clutter the image with static “noise,” making it difficult to visualize the outline of RJ. Therefore it is important to optimize the gain settings when performing the color Doppler examination.

To obtain superior quality regurgitant flow signals, we often found it necessary to use a 2.5 MHz rather than a 3.5 MHz transducer to interrogate areas farthest from the transducer. This is especially important when examining from the apex, in which case the Doppler beam has to traverse the entire longitudinal length of the left ventricle before it reaches the left atrium. The proximity of the left atrium to the chest wall and the transducer in the long axis view may also explain the large number of patients in whom the RJ was visualized by us best in this plane rather than in the A4C view.

Although the large Doppler frequency shifts generated in the left atrium by the high-velocity regurgitant signals produce an easily recognizable distinctive greenish or mosaic pattern of colors (“variance” or disturbed flow), any portion of the regurgitant jet traversed by the Doppler beam at a relatively high interrogation or obtuse angle (i.e., in a nonparallel orientation) will produce lower Doppler frequency shifts. These will be depicted as low-velocity flow patterns that will be simply coded as blue or red signals depending on their direction in a given plane. Thus they could produce an erroneous impression of laminar, nondisturbed flow and may not be recognized as part of the high-velocity RJ. This problem is alleviated by carefully viewing the videotape, in which these apparently low-velocity flow signals would be seen to be continuous with the mosaic main RJ and moving with it in the cardiac cycle in a phasic manner.

Another important consideration is that the color Doppler examination needs to be performed by a fully trained echocardiographer, since the transducer needs to be angled and moved in small increments to obtain the maximal regurgitant signals in any given plane. In our experience, small changes in transducer angulation and motion may produce marked variations in the size of the regurgitant jet, making it mandatory for the
echocardiographer to move and angle the transducer slightly in various directions when examining the flow patterns in each of the three standard planes.

Although we have compared color Doppler findings with angiographic results, the limitations of the latter technique in the assessment of mitral regurgitation are well recognized. It has been recently shown, for instance, that a significant overlap exists when the angiographic grading of mitral regurgitation is compared with catheterization-derived indexes of regurgitant volume.\(^1\) However, the latter technique has several limitations. For instance, the methods used to measure the total left ventricular stroke volume and the forward stroke volume are not identical, one being angiographic and the other Fick or thermodilution. Significant differences have been found when different methods of measuring stroke volume are compared in a given patient.\(^1,4\) and this would undermine the accuracy of this technique, especially in patients with mild mitral regurgitation. Also, the angiographic measurement of stroke volume makes assumptions regarding the geometric shape of the left ventricle, which may not be valid in patients with severe mitral regurgitation. More important, the regurgitant fraction method cannot be used to assess mitral regurgitant fraction in the presence of atrial fibrillation or in patients with associated aortic regurgitation.\(^1\) For this reason, the method was found to be of very limited value in our study because more than half of our patients (42/82, 51\%) had associated aortic regurgitation or atrial fibrillation. Nevertheless, the RJA/LAA\% by color Doppler correlated fairly well with mitral regurgitant fractions obtained by cardiac catheterization and angiography.

It is possible that some of the discrepancies noted between color Doppler and angiographic grading of the severity of mitral regurgitation may be caused by the different loading conditions present at the time of cardiac catheterization in the patient who has been premedicated or sedated. Our experimental work in valve models in vitro has shown that the dimensions and size of the RJ signals are related not only to the size of the defect in the valve but also to the pressure gradi-

\(\text{FIGURE 13. Mitral regurgitant fraction obtained by cardiac catheterization and angiography compared with angiographic grading of mitral regurgitation.}\)

\(\text{FIGURE 14. Maximum RJA by color Doppler compared with left atrial size (LAA), which was averaged from three planes in each patient. Note the good correlation in patients with angiographic grades II and III mitral regurgitation.}\)
ent across the valve. Thus, for a constant valvular defect, the maximum depth and transverse dimensions as well as the area of the RJ signals would be expected to vary significantly depending on the loading conditions. In the clinical setting, studies done in our laboratory in patients with mitral regurgitation have shown that the RJA may show a considerable increase in size during isometric handgrip exercise, resulting in an increase in left ventricular afterload.

Despite its limitations, angiography represents the most widely used and accepted technique in the assessment of patients with mitral regurgitation. Therefore, in the absence of a real gold standard we believe it is reasonable to compare our color Doppler findings with the time-honored angiographic technique, which when performed under ideal conditions has a similar degree of accuracy as the quantitative regurgitant index.

**Conclusion.** Our study shows that color Doppler is useful for the accurate identification and estimation of the severity of mitral regurgitation. A maximum RJA/LAA obtained from three orthogonal planes under 20%, between 20% and 40%, and greater than 40% is consistent with mild, moderate, and severe mitral regurgitation, respectively.

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**References**

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