DIAGNOSTIC TECHNIQUES

Doppler Color Flow Mapping in the Diagnosis of Ventricular Septal Rupture and Acute Mitral Regurgitation After Myocardial Infarction

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Fifty consecutive patients with a newly acquired systolic murmur and severe cardiac decompensation following a recent myocardial infarction (27 with an anterior and 23 with an inferior infarct) were studied by a combination of two-dimensional echocardiography, spectral Doppler and Doppler color flow mapping. The initial ultrasound study defined a ventricular septal rupture in 43 patients and severe isolated mitral regurgitation in 7 patients (5 with papillary muscle rupture and 2 with severe papillary muscle dysfunction). All 50 patients had subsequent confirmation of the diagnosis by either cardiac catheterization or surgical inspection, or both.

Two-dimensional echocardiography alone directly visualized a septal defect in only 17 (40%) of the 43 patients with ventricular septal rupture. In all 43 patients the mitral valve appeared normal on imaging. In six of the seven patients with isolated mitral regurgitation, two-dimensional echocardiography correctly demonstrated the structural abnormality of the mitral valve (five with flail anterior leaflet and one with posterior leaflet prolapse).

The addition of Doppler color flow mapping greatly improved the diagnostic information in both patient groups. In all 43 patients with ventricular septal rupture, Doppler color flow mapping demonstrated both an area of turbulent transseptal flow and a diagnostic systolic flow disturbance within the right ventricle. In the seven patients with isolated papillary muscle rupture or dysfunction, Doppler color flow mapping not only demonstrated the presence of mitral regurgitation in all cases, but also identified the specific mitral leaflet abnormality by defining the direction of the regurgitant jet. However, when the severity of the isolated mitral regurgitation, as graded by Doppler color flow mapping, was compared with that derived from angiography, severity was underestimated by 1 or 2 grades in four patients.

It is concluded that the combination of two-dimensional echocardiography and Doppler color flow mapping is a sensitive and specific technique for the differentiation of postinfarction ventricular septal rupture and isolated acute mitral regurgitation and should now be considered the optimal method for defining the underlying lesion or lesions in patients who develop a systolic murmur in the setting of acute myocardial infarction.

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Doppler color flow mapping has proved to be a highly sensitive diagnostic technique for defining both congenital restrictive ventricular septal defects (15) and chronic mitral regurgitation (16), and its value has been reported in the diagnosis of postinfarction ventricular septal rupture (11,17). However, there is no large series in which Doppler color flow mapping findings have been prospectively correlated with the underlying abnormal morphology over the spectrum of complications of myocardial infarction.

The aims of this study were to assess the diagnostic accuracy of Doppler color flow mapping for differentiating ventricular septal rupture from acute mitral regurgitation in the setting of recent myocardial infarction and to identify any potential benefits and pitfalls in the use of the technique.

Methods

Study patients. Between December 1986 and May 1989, 50 consecutive patients who developed a loud pansystolic murmur after myocardial infarction associated with various degrees of hemodynamic deterioration were referred to one of our participating cardiothoracic centers for evaluation and consideration for surgical intervention. All 50 patients were evaluated by cardiac ultrasound soon after arrival in the respective cardiothoracic unit. The ultrasound systems used in the study included a Toshiba SSH 65A, a Toshiba SSH 160A or a Vingmed CFM 700. Standard parasternal, apical and subcostal cross sections were recorded. The initial two-dimensional echocardiographic study was used to assess left ventricular wall motion abnormalities, mitral valve morphology and the possible presence of a ventricular septal defect. Observed left ventricular wall motion abnormalities were related to the area of the left ventricle involved. These wall segments were then graded as either hypokinetic, akinetic, dyskinetic, aneurysmal or hyperkinetic. In every patient the mitral valve morphology including the subvalve apparatus was assessed by scanning the valve in both the parasternal and the apical long-axis views. To confirm or exclude the presence of a septal defect, the whole ventricular septum was scanned in the apical four chamber, parasternal short-axis and subcostal views by using a procedure previously described by Sutherland et al. (18). Because of the technical difficulties of performing echocardiography in these patients, modified transducer positions and angulations were often required to image the entire septum and to reduce the potential for missing the defect. The presence of a septal rupture was considered definite if an unequivocal, complete, transverse interruption of the septal echo was visualized in one echocardiographic plane.

Doppler recordings. A combination of pulsed and continuous wave Doppler ultrasound was used to demonstrate the presence or absence of mitral regurgitation by scanning the mitral valve from the apex in the standard manner. The presence of a septal rupture was confirmed by pulsed Dopp-
Figure 1. A Doppler color flow map recorded from the apical four chamber view (systolic frame) in a patient with postinfarction rupture of the posteromedial papillary muscle and a flail anterior mitral leaflet. There is an eccentric lateral regurgitant jet that extends from the left ventricle (LV) to the back wall of the left atrium (LA), indicating grade 4/4 mitral regurgitation (see text). RA = right atrium.

Doppler color flow mapping. All Doppler color flow mapping studies were performed in the velocity/variance mode with appropriate gain and filter settings. Doppler color flow mapping was considered diagnostic of mitral regurgitation when, in both apical four chamber and long-axis views, it demonstrated the typical mitral regurgitant systolic jet within the left atrium. The mitral regurgitant jet configuration was described as "central," "eccentric medial" or "eccentric lateral." Central jets originated from the coaptation line of the valve leaflets and were directed centrally within the left atrium. Eccentric medial jets were directed medially toward the interatrial septum and usually indicated a prolapsing posterior valve leaflet. Eccentric lateral jets were directed posterolaterally toward the lateral left atrial wall (Fig. 1) and usually indicated a prolapsing anterior valve leaflet. The severity of mitral regurgitation based on the Doppler color flow mapping information was graded on a scale from 1 to 4 according to the extension of the regurgitant jet into the left atrium as described by Miyatake et al (16).

Cardiac catheterization. Right heart catheterization with a Swan-Ganz catheter was performed in 16 patients either before (8 patients) or at the time of left heart catheterization (8 patients). Pressure recordings and samples for oximetry were taken before any angiographic studies were done. Left ventriculography and coronary arteriography were performed in 22 of the 43 patients with ventricular septal defect and in all 7 patients with mitral regurgitation. An intraaortic counterpulsation balloon was also inserted at the time of left heart catheterization in 20 of the 43 patients with septal defect and in 4 of 7 patients with isolated mitral regurgitation. Left ventriculography was performed in a standard manner with use of both left and right anterior oblique projections. The severity of mitral regurgitation was graded according to the classification of Sellers et al (19).

Surgical or postmortem examination. All 20 patients who did not have invasive studies had confirmation of the diagnosis either by direct surgical inspection (n = 19) or by postmortem examination (n = 1).

Results

Two-Dimensional Echocardiography (Table 2)

Left ventricular wall motion. The detection of abnormal left ventricular wall motion by this technique correctly predicted the site of myocardial infarction in all 50 patients. In every case this correlated with the infarct site as identified by the 12-lead ECG. An aneurysm of the ventricular septum was considered present in 20 of the 43 patients with septal rupture and was defined by the appearance of a bulge of the apical or posterior septum protruding into the right ventricle. Several of the patients with septal rupture exhibited an
abnormal incoordinate contraction pattern of the ventricular septum near the site of rupture that indicated the presence of an associated septal rupture. However, unless a true break in septal continuity was visualized, this was not considered diagnostic of ventricular septal rupture. Hyperkinetic segments opposite the area of infarction were present in 19 of 42 patients with septal rupture. In contrast, all seven patients with isolated severe mitral regurgitation had hyperkinetic wall motion in the noninfarct territory.

Direct visualization of the ventricular septal rupture (Table 3). Direct visualization of a defect in the ventricular septum, using two-dimensional echocardiography alone, was possible in only 17 (40%) of the 43 patients with subsequently proved ventricular septal rupture. Visualization of an anterior trabecular defect (2 of 12, 17%) and an apical septal defect (6 of 16, 38%) proved to be more difficult than that of a posterior septal defect (9 of 15, 60%) using two-dimensional echocardiography alone. In none of the seven patients with isolated acute mitral regurgitation was a defect in the ventricular septum visualized.

Mitral valve morphology (Table 3). Six of the seven patients with isolated acute mitral regurgitation had an obvious morphologic abnormality of the mitral valve on echocardiography and Doppler color flow mapping as correlated with cardiac catheterization or surgical inspection, or both.

| Table 3. Comparative Diagnostic Accuracy of Two-Dimensional Echocardiography and Doppler Color Flow Mapping as Correlated With Cardiac Catheterization or Surgical Inspection, or Both |
|---------------------------------------------|------------------|------------------|
| Patients With Ventricular Septal Rupture (n = 43) | Patients With Isolated Mitral Regurgitation (n = 7) |
| Two-dimensional echocardiography | | |
| Visualization of VSD | 17 (40%) | 0 (0%) |
| Visualization of MV abnormality | 0 (0%) | 6 (86%) |
| Doppler color flow mapping | | |
| Diagnostic of VSD | 43 (100%) | 0 (0%) |
| Correct localization of VSD | 41 (98%) | NA |
| Diagnostic of MR | 4/4 (100%) | 7 (100%) |
| Correct grading of MR severity | 4/4 (100%) | 3 (43%) |

MR = mitral regurgitation; MV = mitral valve; NA = not applicable; VSD = ventricular septal defect.
two-dimensional echocardiography. The abnormalities included a flail anterior leaflet in five cases and posterior leaflet prolapse in one case. In two of the patients with a flail anterior leaflet, a mobile mass of the ruptured papillary muscle could be visualized prolapsing in and out of the left atrial cavity during the cardiac cycle. In the one remaining patient no abnormality of the mitral valve was detected on imaging alone. This patient had poor image quality from both the precordial and subcostal echocardiographic windows, and although the anterior excursion of the anterior mitral leaflet in retrospect was exaggerated, at the time of study it was considered to be within normal limits. In none of the 43 patients with ventricular septal rupture was the morphology of the mitral valve abnormal on two-dimensional echocardiography.

**Doppler Color Flow Mapping**

**Ventricular septal rupture (Table 3).** Doppler color flow mapping, by demonstrating either transseptal flow or the presence of a diagnostic right ventricular flow disturbance, correctly predicted the presence of ventricular septal rupture in all 43 patients with this condition. Information regarding the site of the septal rupture by either surgical inspection or postmortem examination was subsequently available in 42 patients. Doppler color flow mapping correctly demonstrated the site of septal rupture in 41 (98%) of these 42 patients. These were classified as apical in 16 patients, posterior in 15 patients and anterior trabecular in 11 patients. In one patient Doppler color flow mapping suggested an apical septal rupture site, but at surgery the defect was situated in the anterior trabecular septum. Multiple color jets exiting from the right ventricular aspect of the interventricular septum were present in six patients; in two of these, the jets originated from areas of the septum separated by ≥1 cm and indicated the presence of multiple septal defects. In the other four cases multiple jets originated from the same area of the septum (<1 cm apart); three were found to have fenestrated defects at surgery.

**Mitral regurgitation (Table 3).** Isolated mitral regurgitation was demonstrated by Doppler color flow mapping in all seven patients with isolated papillary muscle rupture or dysfunction. In none of these patients was a false positive diagnosis of an associated ventricular septal rupture suggested on Doppler color flow mapping. The regurgitant color jet configuration was classified as central in one patient, eccentric medial in one patient and eccentric lateral in five patients. The direction of the color jet correlated with the morphologic abnormality of the mitral valve as defined by two-dimensional echocardiography in five of the seven patients. One patient with an apparently normal mitral valve on two-dimensional echocardiography had an eccentric lateral color jet suggesting abnormal coaptation involving the anterior leaflet; this was confirmed at surgery. The patient with a central regurgitant color jet had a flail anterior leaflet on the two-dimensional image: this patient also had significant involvement of the posterior leaflet.

*The severity of mitral regurgitation* was defined as grade 2 in one patient, grade 3 in three patients and grade 4 in three patients. All seven patients had grade 4 mitral regurgitation as defined by left ventriculography.

*Four of the 43 patients with ventricular septal rupture* were also found to have coexisting mitral regurgitation with a severity grade between 1 and 2; this was confirmed by left ventriculography. In only one patient in this subgroup was the regurgitant jet of sufficient length to confidently assess its configuration; this patient had an eccentric medial jet that was secondary to an inferior infarction. None of these patients, however, required concomitant mitral valve surgery at the time of ventricular septal rupture repair.

**Discussion**

The results of this study indicate that Doppler color flow mapping is a highly sensitive and specific technique (sensitivity 100%, specificity 100%) when used to differentiate ventricular septal rupture from acute severe mitral regurgitation following acute myocardial infarction. One reason for this high sensitivity is related to the manner in which the Doppler color flow mapping information is generated; the Doppler color information is processed separately from the two-dimensional imaging information and then the two are superimposed to produce the final Doppler color flow map. This means that, in patients with a widespread turbulent jet lesion such as is encountered in postinfarction ventricular septal rupture and mitral regurgitation, high quality color flow information can normally be obtained even when the two-dimensional image is of poor quality. This is particularly relevant in patients with ventricular septal rupture, in whom echocardiography is often technically difficult.

**Ventricular septal rupture.** We have previously reported (11) our initial experience on the value of Doppler color flow mapping in the diagnosis and assessment of ventricular septal rupture. This study demonstrated the superior diagnostic capabilities of Doppler color flow mapping when compared with either two-dimensional echocardiography alone or in combination with pulsed wave Doppler recording. Doppler color flow mapping provided not only a rapid visual diagnosis, but also additional information. It was found to accurately localize the position of the septal defect when correlated with surgical inspection, and it demonstrated the presence of multiple defects and coexisting mitral regurgitation. The experience reported in this study further confirms our previous conclusions. However, one potential pitfall in the use of Doppler color flow mapping in determining the site of septal rupture has been highlighted in this series. In one patient with an anterior trabecular septal defect, a large area of turbulent flow at the right ventricular
apex was incorrectly interpreted as indicating an apical septal defect (Fig. 2). However, this was misleading, and it must be emphasized that it is important to identify the precise area of transseptal flow instead of estimating the right ventricular exit point of the color jet when classifying the septal defect site.

Doppler color flow mapping was of additional benefit in distinguishing different morphologies of postinfarction ventricular septal defects. Complex defect morphologies that were defined in this series included a linear tangential tear across the septum, a localized dissection of the right ventricular septal endocardium, multiple septal defects and single fenestrated defects. In every case these various defect morphologies became apparent only after a reassessment of the two-dimensional image that took into account the Doppler color flow mapping information. These different complex morphologies defined by Doppler color flow mapping were all confirmed at surgery either by direct inspection or by the combined use of intraoperative epicardial echocardiography. Although such complex defects in the ventricular septum can be recognized from the precordial approach, it is our experience that even with additional Doppler color flow mapping, a few will be missed, and optimal information on the precise defect morphology can be derived by using intraoperative epicardial echocardiography at the time of defect repair.

Acute mitral regurgitation. Previous reports (12-14) have described the typical two-dimensional echocardiographic features of papillary muscle rupture. These include a blunted stump of the papillary muscle, a mobile mass of the ruptured head of the papillary muscle, a flail mitral leaflet and a prolapsing mitral leaflet. All but the first of these features were demonstrated in individual patients in this series. We therefore confirm the experience of others that two-dimensional echocardiography can consistently demonstrate the intrinsic mitral valve abnormalities in patients with papillary muscle rupture.

In this series Doppler color flow mapping proved to be highly sensitive for the detection of isolated mitral regurgitation associated with papillary muscle rupture or dysfunction. Its additional value was the ability to demonstrate the eccentricity of regurgitant jets encountered with this lesion. As with degenerative mitral valve prolapse, the direction of the regurgitant jet was related to the underlying mitral leaflet abnormality. A flail anterior leaflet caused a regurgitant jet that was directed toward the posterolateral left atrial wall (Fig. 1) and a prolapsing posterior leaflet resulted in a regurgitant jet that was directed toward the interatrial septum. When both leaflets were involved, the resultant regurgitant jet was centrally directed.

The limitation of Doppler color flow mapping was that, with use of the stated criteria, it frequently underestimated the severity of mitral regurgitation when results were compared with those of left ventriculography. There are several possible reasons for this. First, the regurgitant jets were virtually all eccentric in direction within the left atrium and therefore their true extent may not have been appreciated. These jets can move out of the plane of the echocardiographic cross section, thus appearing shorter in length and smaller in area. Second, the compliance of the left atrium in these patients may be reduced when compared with that of patients with chronic mitral regurgitation because the left atrium has not had time to enlarge. Third, the left ventricular to left atrial systolic pressure gradient is reduced because of a combination of low left ventricular systolic pressure and a high left atrial V wave. It is likely that a combination of all these factors is responsible for the apparent reduction in the color encoded area of flow disturbance within the left atrium.

However, despite the aforementioned inherent limitations of the Doppler color flow mapping technique in assessing the severity of mitral regurgitation, when the morphology of the mitral valve, the hyperdynamic left ventricular wall motion and the eccentricity of the regurgitant jets were taken into consideration, the diagnosis of acute severe isolated mitral regurgitation could be inferred.

Indications for left ventriculography. The complete diagnostic information derived from combined two-dimensional echocardiography and Doppler color flow mapping studies not only proved accurate and reliable in the definition of the postinfarction complications in this series, but also provided information on the structural and functional status of the left ventricle in every case. We therefore suggest that routine left ventriculography is not necessarily a prerequisite in the preoperative management of these cases. This procedure is not without risk (20,21) and, if possible, should be avoided, especially in patients in severe cardiogenic shock who have ventricular septal rupture. It is conceivable that a small number of patients with papillary muscle rupture might require left ventriculography should the combined two-dimensional echocardiography and Doppler color flow mapping studies be at variance with the clinical estimation of the severity of regurgitation. The requirement for invasive investigation to perform coronary arteriography and the need for concomitant coronary bypass grafts at the time of defect repair is as yet unresolved and is beyond the scope of this report.

Conclusions. The combination of two-dimensional echocardiography and Doppler color flow mapping performed at the bedside can rapidly and reliably make a precise diagnosis of the underlying pathology in patients who develop a loud systolic murmur after myocardial infarction. On the basis of this information, it is our experience that appropriate clinical management decisions can be made in every case. We also suggest that left ventriculography provides little additional information in the preoperative assessment of patients with postinfarction ventricular septal rupture.
References


