Measurement of mitral regurgitation by Doppler echocardiography

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SUMMARY In an attempt to develop a new approach to the non-invasive measurement of mitral regurgitation, Doppler echocardiography and left ventriculography were performed in 20 patients without valvar heart disease (group A) and in 30 patients with pure mitral regurgitation (group B). Volumetric flows through the aortic and the mitral orifices were determined by Doppler echocardiography. Aortic flow (AF) was calculated as the product of the aortic orifice area and the systolic velocity integral. The mitral flow (MF) was calculated as the product of the corrected mitral orifice area and the diastolic velocity integral. The mitral regurgitant fraction (RF) was calculated as RF = 1 – AF/MF. In group A aortic and mitral flow were very similar and the difference between the two did not differ significantly from zero. In group B the mitral flow was significantly larger than the aortic flow. There was a good correlation (r = 0.82) between the regurgitant fraction determined by Doppler echocardiography and the regurgitant grades determined by left ventriculography. The regurgitant fraction increased significantly with each grade of severity. These results show that Doppler echocardiography can be used to give a reliable measure of both aortic and mitral flow. This technique is a new and promising approach to the non-invasive measurement of mitral regurgitation.

Volumetric blood flow through the semilunar and atrioventricular valves can be measured by Doppler echocardiography.1–3 Methods based on measurement of the aortic and the mitral orifices give a reliable estimate of cardiac output.4 5 We have found that cardiac output calculated from the mitral flow determined by Doppler echocardiography was higher than that measured by the Fick method in patients with mitral regurgitation.5 This raises the possibility that in these patients measurement of both aortic and mitral flow by Doppler echocardiography might be used to assess mitral regurgitation. We assessed mitral regurgitation by Doppler echocardiography and compared the results with those obtained by left ventriculography.

Patients and methods

STUDY POPULATION
Fifty patients who underwent diagnostic left heart catheterisation were included in the study. They were divided into two groups according to clinical and Doppler echocardiographic findings. Group A consisted of 20 patients (17 men and three women, aged 19–60 years, mean 47) without evidence of valvar heart disease. Group B comprised 30 patients (17 men and 13 women, aged 23–67 years, mean 55) with pure mitral regurgitation. Clinical diagnoses in group A were coronary artery disease (17 patients), atrial septal defect (two patients), and congestive cardiomyopathy (one patient). The cause of the mitral regurgitation in group B was coronary artery disease in 20 patients, congestive cardiomyopathy in seven patients, mitral prolapse in two patients, and atrial septal defect in one patient. All except two patients in group A had normal left ventricular function.
Doppler echocardiography

A phase array cross sectional instrument (IREX III) with a 2-5 MHz transducer was used for both cross sectional and M mode recordings. A multifrequency (1-10 MHz) Doppler instrument (ALFRED, Vingmed) connected to a Chirp-Z transform spectral analyser (DAISY, Vingmed) and a transducer of 2 MHz was used for velocity measurements. The Doppler instrument can be operated either in the pulsed mode to measure velocities up to 2.8 m/s or in the continuous mode to measure velocities up to 8.1 m/s, but there is loss of range resolution in the continuous mode. The sample volume in the pulsed mode is approximately 8 mm in diameter and 5 mm in length. The Doppler outputs included analogue curves of the mean and the maximal velocities, the spectral display, and the amplitude of Doppler signals. A direct audio output aided the identification of the best transducer positions.

To record aortic flow, the left parasternal long axis view was imaged with the patient in the left lateral position. The transducer position was adjusted to obtain the maximal aortic orifice diameter and the images were recorded on video tapes. The Doppler probe was then placed in the suprasternal position with the patient in the supine position. The continuous mode was first used to detect the aortic flow signals and then the pulsed mode used to locate the aortic valve. With the aid of the audio signals the probe was angled carefully to identify the highest aortic flow velocities; these were found immediately above the aortic valve in a position where there was no interference from valve movements. A Doppler recording was accepted as being technically adequate if a high frequency whistling sound was heard while a smooth and high velocity curve was being recorded. The electrocardiogram, the phonocardiogram, the spectral display, and the amplitude of Doppler signals were simultaneously recorded on an IREX III strip chart recorder at a paper speed of 50 mm/s.

To record mitral flow, the left parasternal short axis view at the level of the mitral valve was imaged with the patient in the left lateral position. The transducer was manipulated to image the largest mitral valve orifice area and a derived M mode echocardiogram was obtained by adjusting the M mode cursor across the middle of the mitral valve orifice.

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(ejection fraction ≥ 50%), while 22 patients (73%) in group B had left ventricular dysfunction (ejection fraction < 50%). All patients were in sinus rhythm. Doppler echocardiographic measurement of the aortic and mitral flow and left ventriculography were performed independently by three investigators and the results were not compared until after the study was completed.

Left ventriculography

All patients underwent left heart catheterisation within 48 hours of Doppler echocardiography. Left ventriculography was performed in the right oblique projection with an injection of 45 ml Omnipaque (iohexol) at a flow rate of 15 ml/s. The severity of mitral regurgitation was graded on a four point scale—grade 0, absence of regurgitation; grade 1, mild regurgitation; contrast cleared at the next diastole without total opacification of the left atrium; grade 2, moderate regurgitation; contrast cleared more slowly with total left atrial opacification which remained fainter than that of the left ventricle; grade 3, severe regurgitation with total and immediate left atrial opacification equal to that of the left ventricle.

Data analysis

Doppler echocardiographic recordings were analysed by two different investigators who calculated the aortic and the mitral flow independently by means of a digitising computer system (CARDIO 80, Kontron). We used the leading edge to leading edge principle to measure the aortic orifice diameter4 at the level of attachment of the aortic valve cusps (Fig. 1a). The results of three consecutive cardiac cycles were averaged to calculate the aortic orifice area (AOA) as: AOA = π AOD³/4, where AOD is the aortic orifice diameter. The systolic velocity curves were integrated along the darkest portion of the spectrum and the integration was ended at the onset of the second heart sound (Fig. 1b). The results of 10 consecutive cardiac cycles were averaged to obtain the systolic velocity integral (SVI) and the aortic flow (AF) was finally calculated as: AF = AOA × SVI. The maximal mitral valve orifice during early diastole was digitised along the black-white interface and the results of six consecutive cardiac cycles were averaged to
obtain the maximal mitral orifice area (MMA) (Fig. 2a). The derived M mode echocardiogram of the mitral valve was digitised over 10 consecutive cardiac cycles to obtain the mitral orifice opening ratio (MOR) (Fig. 2b). The corrected mitral orifice area (CMA) was calculated as: CMA = MMA × MOR. The diastolic velocity curves were integrated along the darkest portion of the spectrum and the integration was stopped at the onset of the first heart sound (Fig. 2c). Ten consecutive cardiac cycles were averaged to obtain the diastolic velocity integral (DVI), and the mitral flow (MF) was finally calculated as: MF = CMA × DVI.

Theoretically, in patients without valvar regurgitation the aortic flow should equal the mitral flow, while in patients with pure mitral regurgitation the mitral flow (MF) represents the total stroke volume and the aortic flow (AF) equals the effective stroke volume. The mitral regurgitant fraction (RF) was thus calculated in both groups as: RF = 1 - AF/MF.

**STATISTICS**

Statistical analysis was performed by Student's paired t test and correlation and linear regression analysis. Aortic and mitral flows were compared by the method of Altman and Bland. Data are expressed as mean and one standard deviation.

**Results**

**DOPPLER ECHOCARDIOGRAPHY**

Technically adequate Doppler echocardiographic recordings were obtained from all patients in group A and from 29 (97%) patients in group B. One patient was excluded from group B because an echocardiographic short axis view was inadequate. Results of Doppler echocardiography in patients in the two groups are given in Tables 1 and 2.

In group A the aortic orifice area ranged from 3·02 cm² to 5·72 cm² (4·34(0·74) cm²), the systolic velocity integral from 17·0 cm to 28·9 cm (22·6(3·04) cm), and the calculated aortic flow from 58 cm³ to 140 cm³ (98(20) cm³). The corrected mitral orifice area varied between 3·67 and 6·55 cm² (5·09(0·93) cm²), the diastolic velocity integral between 12·3 cm and 26·0 cm (19·5(3·24) cm), and the calculated mitral flow between 50 cm³ and 143 cm³ (99(22) cm³).

Aortic flow variables were compared with those of mitral flow in group A. The corrected mitral orifice area was significantly larger than the aortic orifice area (5·09(0·93) cm² vs 4·34(0·74) cm², p < 0·001, Fig. 3a). On the other hand, the diastolic velocity integral was significantly smaller than the systolic velocity integral (19·5(3·24) cm vs 22·6(3·04) cm, p < 0·001, Fig. 3b). Mean aortic and mean mitral flows (98(20) cm³ vs 99(22) cm³) were not significantly different (Fig. 3c). The difference between the aortic and the mitral flow was plotted against the mean of the two measurements (Fig. 4). The relative bias given by the mean of these differences between the two measurements was 1·0 cm³, and the estimate of error given by the standard deviation of these differences was 7·51 cm³. The difference between the two measurements did not correlate with the mean of the two measurements and did not differ significantly from zero. The calculated regurgitant fraction in this group was 0·13(7·9)% with a range from -16% to +14%.

In group B the aortic orifice area ranged from 2·09 to 6·92 cm² (4·16(0·93) cm²), the systolic velocity integral from 8·0 to 26·9 cm (16·5(5·49) cm), and the calculated aortic flow from 36 to 111 cm³. The corrected mitral orifice area varied between 3·27 and 8·13 cm² (5·33(1·13) cm²), the diastolic velocity integral between 10·2 and 38·2 cm (19·9(6·05) cm), and the calculated mitral flow between 42 and 230 cm³ (108(48) cm³).
Aortic flow variables were compared with those of mitral flow in group B. The corrected mitral orifice area was significantly larger than the aortic orifice area (5-33(1-13) cm² vs 4-16(0-93) cm², p < 0.001, Fig. 3a). In contrast to group A, however, the diastolic velocity integral was significantly larger.

### Table 1  Results of Doppler echocardiography in group A

<table>
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<tr>
<th>Case</th>
<th>Diagnosis</th>
<th>AOA (cm²)</th>
<th>SVI (cm)</th>
<th>AF (cm²)</th>
<th>CMA (cm²)</th>
<th>DVI (cm)</th>
<th>MF (cm²)</th>
<th>RF (%)</th>
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<td>123</td>
<td>6-55</td>
<td>20-0</td>
<td>131</td>
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AOA, aortic orifice area; SVI, systolic velocity integral; AF, aortic flow per cardiac cycle; CMA, corrected mitral orifice area; DVI, diastolic velocity integral; MF, mitral flow per cardiac cycle; RF, regurgitant fraction.
than the systolic velocity integral (19.9±6.05 cm vs 16.5±5.49 cm, p<0.001, Fig. 3b). The mitral flow was larger than the aortic flow in all patients and there was a significant difference between the two means (108.48 cm³ vs 67.24 cm³, p<0.001, Fig. 3c). The calculated mitral regurgitant fraction was 34(14)% with a range from 13% to 81%.

**LEFT VENTRICULOGRAPHY**

Technically adequate left ventriculograms were obtained from all patients in both groups. In group A no cases of aortic or mitral valve disease were found by cineangiography. In group B one patient had grade 0, nine had grade 1, 10 had grade 2, and nine had grade 3 mitral regurgitation. No associated aortic valve disease was found in these patients.

The regurgitation fraction derived from Doppler echocardiography compared with the regurgitant grades obtained by left ventriculography in the 28 patients in whom mitral regurgitation was demonstrable by both techniques. In the three subgroups with regurgitation of grades 1, 2, and 3, the regurgitant fraction ranged from 13% to 31%, 30% to 43%, and 38% to 81%, with the mean values being 21.1±6.0%, 33.7±4.2%, and 49.4±13.0% respectively. The difference in the mean regurgitant fraction between consecutive grades was highly significant (p<0.001), and there was a good correlation between the regurgitant fraction and the regurgitant grades (r=0.82, p<0.001, Fig. 5), although the values of regurgitant fraction varied widely in grade 3 and there was some overlap of regurgitant fraction between consecutive grades.

**Discussion**

Doppler echocardiography has proved to be the most accurate of current non-invasive techniques for detection of mitral regurgitation. The usefulness of this technique in quantifying mitral regurgitation has not, however, been established. Although several methods have been described, the proposed indices are still qualitative or semiquantitative. We measured the volumetric flow through the aortic and the mitral orifice by Doppler echocardiography in an attempt to develop a new approach to quantitating mitral regurgitation. Both the aortic and the mitral orifice models have been validated against established invasive methods in our previous studies. The similarity between the aortic and the mitral flow measurements in group A patients who did not have valvar heart disease confirmed the reliability of the two models for volumetric flow measurements. Similar results have been reported by Lewis et al. In contrast, Loeber et al reported a poor correlation between the two measurements. Use of different methods for determining the aortic cross sectional area and for correcting the diastolic variations of the mitral valve orifice area, together with differences between study...
Fig. 3  (a) Comparison between corrected mitral orifice area (CMA) and aortic orifice area (AOA) in groups A and B. (b) Comparison between diastolic velocity integral (DVI) and systolic velocity integral (SVI) in groups A and B. (c) Comparison between aortic flow (AF) and mitral flow (MF) in groups A and B.
Measurements indicate two lines may account for some of the differences between these studies.

In patients without mitral regurgitation, the corrected mitral orifice area was significantly larger than the aortic orifice area, while the diastolic velocity integral was significantly smaller than the systolic velocity integral, producing similar aortic and mitral flow measurements. On the other hand, in patients with mitral regurgitation both the corrected mitral orifice area and the diastolic velocity integral were significantly larger than the corresponding aortic orifice area and the systolic velocity integral, and thus the resulting mitral and aortic flow measurements were significantly different. These results suggest that the increased mitral flow compared with the aortic flow in patients with mitral regurgitation is mainly caused by the relative changes of flow velocities through the two valve orifices.

We compared the results of Doppler echocardiography with those of left ventriculography, although this latter method of assessing mitral regurgitation is limited by its semiquantitative nature. Most of our patients with mitral regurgitation had poor left ventricular function and pronounced left ventricular regional wall dyskinesia due to coronary artery disease, which made measurement of mitral regurgitation either by combined angiography and Fick method or by radionuclide ventriculography rather difficult and subject to error. In group B there was a good correlation between Doppler echocardiography and left ventriculography for the qualitative detection of mitral regurgitation except for one case. In case 27 of group B the mitral regurgitant jet detected by the Doppler technique did not last throughout systole and the calculated regurgitant fraction was only 18%. During left ventriculography in this patient, apparent mitral regurgitation was seen only during a burst of extrasystoles induced by injection of contrast medium. Although difficult to explain, the discrepancy between the two techniques in this case might be the result of the Doppler technique being more sensitive than cineangiography in detecting mild mitral regurgitation. Nevertheless, in 28 patients mitral regurgitation was detected by both techniques. There was a good correlation between the regurgitant fraction by Doppler echocardiography and the regurgitant grades by left ventriculography, and there was a significant difference in the regurgitant fraction between consecutive grades. These results indicate that our Doppler echocardiographic method is able to distinguish mild, moderate, and severe mitral regurgitation. On the other hand, the values of regurgitant fraction varied widely in grade 3 and
there was some overlap of regurgitant fraction between consecutive grades. Our Doppler echocardiographic method is probably more precise than left ventriculography for estimating mitral regurgitation especially in patients with severe regurgitation.18

The Doppler method has several limitations. It can only be used in cases of pure mitral regurgitation. Associated mitral stenosis makes correct measurement of the mitral flow difficult. Similarly, the aortic flow measurement is unreliable in the presence of aortic stenosis, and the calculated regurgitant fraction is misleading when combined aortic and mitral regurgitation is present.

Our study shows the reliability of Doppler echocardiography for the determination of both aortic and mitral volumetric flow. This method provides a new and promising approach to the non-invasive measurement of mitral regurgitation.

References


