Doppler tissue velocity sampling improves diagnostic accuracy during dobutamine stress echocardiography for the assessment of viable myocardium in patients with severe left ventricular dysfunction

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Background Both nuclear imaging with F18-fluorodeoxyglucose and dobutamine stress echocardiography have been used to identify viable myocardium, although dobutamine-stress echocardiography has been demonstrated to be the less sensitive of the two.

Aim To compare the accuracy of pulsed-wave Doppler tissue sampling with dobutamine-stress echocardiography for the detection of viable myocardium, using F18-fluorodeoxyglucose imaging as a reference.

Methods Forty patients with chronic coronary artery disease and left ventricular dysfunction (mean ejection fraction 33 ± 11%), underwent F18-fluorodeoxyglucose imaging, dobutamine-stress echocardiography and pulsed-wave Doppler tissue sampling. Evaluation was performed using a six-segment model.

Results Visual assessment by resting echo was feasible in 230 out of 240 segments (96%); 177 (77%) segments showed severe dyssynergy at rest. F18-fluorodeoxyglucose imaging showed viability in 95 (54%) segments while 82 (46%) were non-viable. Ejection phase velocity at rest was not significantly different; ejection velocities during low-dose and peak-dose dobutamine, however, were significantly higher in viable myocardium (8.6 ± 2.9 vs 6.0 ± 1.8 and 9.3 ± 3.1 vs 6.2 ± 2.1 cm.s⁻¹). Using receiver operating characteristic curves the optimal cut-off value for viability assessment was an increase in the ejection phase velocity low-dose of 1 ± 0.5 cm.s⁻¹, while 0 ± 0.5 cm.s⁻¹ predicted non-viability. The sensitivity and specificity (95%CI) of pulsed-wave Doppler tissue sampling and dobutamine-stress echocardiography for the prediction of viability was respectively 87% (82–92) vs 75% (67–81) (P<0.05) and 52% (44–59) vs 51% (45–59) (P=ns).

Conclusions The sensitivity of pulsed-wave Doppler tissue sampling is superior to dobutamine-stress echocardiography for the assessment of myocardial viability.

Key Words: Pulsed-wave Doppler tissue sampling, FDG-SPECT; dobutamine-stress echocardiography; myocardial viability.

See page 1039 for the Editorial comment on this article

Introduction

The presence of dysfunctional but viable myocardium in patients with severe left ventricular dysfunction has therapeutic implications since revascularization may improve both functional status and survival[8]. Among the different techniques used to demonstrate myocardial viability, much experience has been gained with nuclear imaging using F18-fluorodeoxyglucose or dobutamine stress-echocardiography and the higher sensitivity of F18-fluorodeoxyglucose imaging has been demonstrated[2]. Moreover, F18-fluorodeoxyglucose imaging allows semi-quantitative analysis, while
dobutamine–stress echocardiography relies on subjective visual interpretation of wall motion[3]. Pulsed-wave Doppler tissue sampling provides a quantitative parameter of myocardial contraction of the vectorial sum of contraction velocities of myocardial fibres (i.e. longitudinal and equatorially contracting fibres) between the base and apex[4–6]. The importance of measuring longitudinal myocardial contraction was based on the observation that both endocardial inward motion and longitudinal contraction contribute equally to the ejection fraction[7].

In the present study we compared the use of pulsed-wave Doppler tissue sampling with dobutamine–stress echocardiography for the identification of myocardial viability in patients with chronic coronary artery disease and severe left ventricular dysfunction, using F18-fluorodeoxyglucose-SPECT as a reference method[8].

Methods

Patients

The study population comprised 40 patients (29 males, mean age 56 ± 9 years) with reduced left ventricular function (mean reduced left ventricular ejection fraction 33 ± 11%) who underwent both dobutamine–stress echocardiography/pulsed-wave Doppler tissue sampling and F18-fluorodeoxyglucose-SPECT for the evaluation of viable myocardium (Table 1).

Cardiac disease, potentially interfering with either cardiac preload or afterload (e.g. valvular heart diseases, pulmonary or systemic hypertension, cardiovascular shunts) was a criterion for exclusion.

Resting two-dimensional echocardiography

All echocardiograms were performed with an ATL HDI 3000 imaging system equipped with a 1-8 MHz transducer using second harmonic imaging to optimize endocardial border visualization. Standard parasternal long- and short-axis views were obtained as were apical long-axis two- and four-chamber views, as described by the American Society of Echocardiography[9]. The left ventricle was divided into six segments, (posterior septum, anterior septum, lateral, inferior, anterior, and posterior). Each segment was divided into three subsegments; wall motion was scored by the pattern displayed by two-thirds of the subsegments.

Pulsed-wave Doppler tissue sampling

Beta-blocker administration was not interrupted before testing. Pulsed-wave Doppler tissue sampling was performed with a Toshiba Powervision echocardiographic imaging system, by using a 3–7 MHz probe, with a pulse repetition frequency of 4–5–6.0 KHz. The temporal resolution of pulsed-wave Doppler tissue sampling was 4–3 ms. A sample volume of 4 mm was used. The continuous measurement of velocity of the myocardium close to the mitral annulus was sampled in apical views (posterior septum, anterior septum, lateral, inferior, anterior, and posterior wall) during a minimum of five consecutive beats in order to minimize the variability induced by respiration. The depth of the sample volume of every wall was kept constant during dobutamine–stress echocardiography to make sure that left ventricular myocardium was sampled close to the mitral annulus.

The Doppler velocity profiles, electrocardiogram and phonocardiogram tracings were simultaneously stored on videotape. All the measurements were performed offline using a computer-assisted drawing system. The velocity values (cm·s⁻¹) were obtained on calibrated still frames by manually measuring the distance between the zero baselines and the peak Doppler profile of the ejection phase, early (E) and late diastole (A) in reference to both the electrocardiogram and phonocardiogram. The E/A ratio was also calculated. Cardiac cycles with extrasystolic, post-extrasystolic beats or any rhythm disturbance were excluded. Recordings and measurements were made at baseline, low dose (10 μg·kg⁻¹·min⁻¹) and peak dobutamine infusion rate.

Dobamime stress echocardiography

Beta-blocker administration was not interrupted before testing. After baseline echocardiography, dobutamine was infused at a starting dose of 5 μg·kg⁻¹·min⁻¹ for 5 min, followed by 10 μg·kg⁻¹·min⁻¹ for 5 min (low-dose stage). Dobutamine was then increased by 10 μg·kg⁻¹·min⁻¹ every 3 min up to a maximum dose of 40 μg·kg⁻¹·min⁻¹. Atropine (1–2 mg) was added at the end of the last stage if the target heart rate (85% of the maximal predicted heart rate) had not been achieved. Images were acquired continuously and recorded on tape at the end of every dose-step. In addition the baseline, low-dose, peak stress, and recovery images (standard apical and short-axis views) were displayed in a cineloop format. End-points for interruption of the test were: (1) achievement of target heart rate; (2) maximal dose of both dobutamine and atropine; (3) extensive new wall motion abnormalities; (4) horizontal

Table 1  Clinical characteristics of patients evaluated by Pulsed-wave Doppler tissue Sampling and dobutamine–stress echocardiography

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number of Patients (%)</th>
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<tr>
<td>Previous MI</td>
<td>26 (65)</td>
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<tr>
<td>History of angina pectoris</td>
<td>31 (78)</td>
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<tr>
<td>Beta-blocker therapy</td>
<td>14 (35)</td>
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<tr>
<td>Ace inhibitors</td>
<td>29 (73)</td>
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or downsloping ST-segment depression (0.2 mV 80 ms after the J-point compared with the baseline); (5) severe angina; (6) symptomatic reduction in systolic blood pressure >40 mmHg from baseline; (7) hypertension (blood pressure >240/120 mmHg); (8) significant arrhythmias or (9) any serious side effect regarded as being due to dobutamine infusion.

**Echocardiographic analysis**

The left ventricle was divided into six segments, (posterior septum, anterior septum, lateral, inferior, anterior, and posterior). Each segment was divided into three subsegments and visually scored by two experienced reviewers (R.R. and D.P., blinded to the F18-fluorodeoxyglucose-SPECT data) for both systolic wall thickening and inward wall motion. Wall motion was scored by the pattern displayed by two-thirds of the subsegments. A 5-point scoring system (1=normokinesis; 2=mild hypokinesis; 3=severe hypokinesis; 4=akinesis and 5=dysskinesis) was used. Segments with normal wall motion or mild hypokinesia were considered normal and viability was assessed only in the severely dysfunctional segments (severe hypokinesia, a- or dyskinesis; 4) types of wall motion responses were observed during the infusion of dobutamine: (1) biphasic pattern: improvement of wall motion during low-dose with worsening at high-dose; (2) worsening: deterioration of wall motion without initial improvement; (3) sustained improvement: improvement of wall motion at low- or high-dose dobutamine; (4) no change: unchanged wall motion. Severely dysfunctional segments exhibiting a biphasic response, worsening or sustaining improvement were considered viable, whereas the severely dysfunctional segments with unchanged wall motion were considered scar tissue. The inter- and intra-observer concordance of the resting wall motion score was, respectively, 94% and 97%, whereas the inter- and intra-observer concordance for the response of wall motion during dobutamine infusion was 92% and 94% respectively.

**F18-fluorodeoxyglucose-SPECT imaging**

Patients received an intravenous dose of 600 MBq $^{99m}$technetium-tetrofosmin to evaluate resting regional perfusion. To enhance cardiac F18-fluorodeoxyglucose uptake, the patients received 500 mg Acipimox (Byk, The Netherlands) orally, followed by a carbohydrate-enriched meal. Acipimox is a potent nicotinic acid derivative that reduces plasma levels of free fatty acids, thereby stimulating cardiac glucose (and F18-fluorodeoxyglucose) uptake. This meal stimulated endogenous insulin release, thereby further promoting cardiac glucose (and F18-fluorodeoxyglucose) uptake. Several studies have shown that this approach yields an excellent image quality, comparable to that obtained with hyperinsulinaemic glucose clamping.10,11] F18-fluorodeoxyglucose (185 MBq) was injected 60 min after the meal. A 45-min period after F18-fluorodeoxyglucose injection was allowed for myocardial F18-fluorodeoxyglucose uptake, followed by the dual-isotope simultaneous acquisition SPECT. Cardiac medication was not discontinued for the SPECT study.

Data acquisition was performed with a triple-head gamma camera system (Picker Prism 3000 XP, Cleveland, OH, U.S.A.) equipped with 511 keV collimators. The energies were centred on the 140 keV photon peak of $^{99m}$technetium-tetrofosmin with a 15% window and one the 511 keV photon peak of F18-fluorodeoxyglucose with a 15% window. Imaging was performed over 360° (120 sectors of 3°) with a total imaging time of 32 min. Data were stored in a 64 × 64, 16-bit matrix. The raw scintigraphic data were reconstructed by filtered back projection using a Butterworth filter (cut-off frequency at 0.17 cycle/pixel, of order 3-5). No attenuation correction was employed. Further reconstruction yielded standard long- and short-axis projections perpendicular to the heart-axis. Reconstructed slices were 8 mm in all projections. The perfusion and F18-fluorodeoxyglucose short-axis slices were adjusted to peak myocardial activity (100%). The myocardium was divided into six segments (matching the echocardiographic segments, including anterior, lateral, posterior, inferior, posterior septum and anterior septum). Segments were divided into four categories (assessed visually with the assistance of normalizer software). Four types of wall motion responses were observed during the infusion of dobutamine: (1) biphasic pattern: improvement of wall motion during low-dose with worsening at high-dose; (2) worsening: deterioration of wall motion without initial improvement; (3) sustained improvement: improvement of wall motion at low- or high-dose dobutamine; (4) no change: unchanged wall motion. Severely dysfunctional segments exhibiting a biphasic response, worsening or sustaining improvement were considered viable, whereas the severely dysfunctional segments with unchanged wall motion were considered scar tissue. The inter- and intra-observer concordance of the resting wall motion score was, respectively, 94% and 97%, whereas the inter- and intra-observer concordance for the response of wall motion during dobutamine infusion was 92% and 94% respectively.

**Statistical analysis**

Unless specified, data were expressed as mean values ± SD. Comparison of continuous variables was performed with the Student’s t-test. Comparison of proportions was performed with the chi-square test and the Fisher’s exact tests. Sensitivity and specificity were presented with their corresponding 95% confidence interval (CI). Kappa value was also calculated.

To assess the optimal cut-off point of pulsed-wave Doppler tissue sampling assessed ejection velocity at low dose and at peak dose dobutamine for the detection of myocardial viability, we used receiver operator’s characteristics (ROC) curve. In these curves, the sensitivity vs specificity of a test was plotted, in which the sensitivity is a fraction of the positive classification for all patients who satisfy the viability criteria of F18-fluorodeoxyglucose-SPECT and specificity is the
fraction of all negative classifications for all patients who satisfy the non-viability criteria of F18-fluorodeoxyglucose-SPECT. A P value <0·05 was considered significantly.

Results

Baseline characteristics

Visual assessment by resting echo was feasible in 230 out of 240 segments (96%). One hundred and seventy seven (77%) segments showed severe dyssynergy at rest; severe hypokinesia in 115 (65%); akinesis in 61 (34%); and dyskinesia in 1 (0·6%). Per patient the mean number of dysfunctional segments was 4·4 ± 2·5. During dobutamine infusion pulsed-wave Doppler tissue sampling could be assessed in 227/240 (95%) segments and wall motion patterns could be scored in 230/240 (96%). The analysis of F18-fluorodeoxyglucose-SPECT was feasible in all 240 segments.

F18-fluorodeoxyglucose-SPECT

Ninety-five out of 177 severely dyssynergic segments were viable (54%); 57 had normal perfusion (32%); 20 experienced a mild reduction in perfusion and F18-fluorodeoxyglucose uptake (11%); there was a mismatch in 18 (10%). Non-viability was present in 82 segments (46%) (Fig. 1).

Pulsed-wave Doppler tissue sampling

The feasibility of the anterior wall, anterior septum, posterior, inferior, lateral, posterior septum was 85%, 90%, 93%, 100%, 100%, and 100%, respectively. Analysis of the pulsed-wave Doppler tissue sampling velocity profile showed a significant morphological variation for each wall and each dobutamine step. Velocity patterns assessed at rest, low dose and at peak dobutamine are presented in Table 2. For each segment, pulsed-wave Doppler tissue sampling recognized four patterns of contraction (Fig. 2). The E/A ratio was not feasible in 15 patients (38%) at peak stress, because of superimposition between A and E waves, thus limiting the feasibility of pulsed-wave Doppler tissue sampling diastolic evaluation at peak stress to 62%.

Dobutamine–stress echocardiography

The 177 severely dissynergic segments exhibited four different patterns of wall thickening (Fig. 3). Ninety-seven segments (55%) were considered non-viable.

Pulsed-wave Doppler tissue sampling vs F18-fluorodeoxyglucose-SPECT

Improvement of ejection phase velocities at low dose and peak stress dobutamine for viability assessment were classified into two patterns with the highest sensitivity and specificity based on ROC curves using F18-fluorodeoxyglucose-SPECT as a reference. Viability by pulsed-wave Doppler tissue sampling at low-dose corresponded with an improvement of velocity of $0\pm0·5\text{ cm} \cdot \text{s}^{-1}$ (n=129) (73%). Non-viability corresponded with no improvement ($0\pm0·5\text{ cm} \cdot \text{s}^{-1}$ (n=48) (27%). Pulsed-wave Doppler tissue sampling has a sensitivity of 87% (82–92), and a specificity of 52% (44–59) for the prediction of viable myocardium.

Viability by pulsed-wave Doppler tissue sampling at peak-dose corresponded with an improvement of velocity of $0\pm0·5\text{ cm} \cdot \text{s}^{-1}$, with a sensitivity of 64% (58–71), and a specificity of 62% (56–69). However, these data added no diagnostic value to pulsed-wave Doppler tissue sampling for the assessment of myocardial viability ($P$=ns).

Agreement between pulsed-wave Doppler tissue sampling and dobutamine–stress echocardiography vs F18-fluorodeoxyglucose-SPECT

Mean ejection velocity values at low dose dobutamine were more increased in viable than non-viable walls (Table 3). This increase, $1\pm0·5\text{ cm} \cdot \text{s}^{-1}$, compared to $0\pm0·5\text{ cm} \cdot \text{s}^{-1}$, exhibited an incremental value to
Table 2  Pulsed Doppler mean ejection phase velocities (cm.s⁻¹ ± SD) and E/A ratios of each left ventricular wall during dobutamine stress echocardiography. (1) Viable myocardium, as assessed by F-18-fluorodeoxyglucose-SPECT, reveals higher ejection phase velocities than (2) non-viable myocardium both at low dose and peak dobutamine. No significant differences are shown by rest ejection phase velocities and by E/A ratio

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<td>7 8 ± 2 6</td>
<td>9 8 ± 3 2*</td>
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<td>9 3 ± 3 1*</td>
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<td>9 3 ± 3 1*</td>
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E/A rest (1) | E/A Id (1) | E/A peak (1) | E/A rest (2) | E/A Id (2) | E/A peak (2) |
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A=anterior wall; A=late diastole; AS=anterior septum; E=early diastole; EJ=ejection phase; I=inferior wall; L=lateral wall; Id=low dose; P=posterior wall; PS=posterior septum; (1) viable segments; (2) non-viable segments; *P<0.05.

Figure 2  Pie-chart showing pulsed-wave Doppler tissue sampling patterns of 177 severely dysynergic segments: sustained improvement n=102 (58%) ( ), biphasic n=20 (11%) ( ), late worsening n=7 (4%) ( ), no change n=48 (27%) ( ).

Figure 3  Pie-chart showing DSE patterns of 177 severely dysynergic segments: sustained improvement n=48 (27%) ( ), biphasic n=20 (11%) ( ), late worsening n=12 (7%) ( ), no change n=97 (55%) ( ).

dobutamine–stress echocardiography for the diagnosis of myocardial viability. The sensitivity of dobutamine–stress echocardiography and pulsed-wave Doppler tissue sampling was 75/87%, respectively (P<0.05), and specificity was 51/52%, respectively (P=ns) (Table 3).

The E/A ratio showed a regional variation. However, E/A ratio changes from rest to low dose failed to predict myocardial viability.

Discussion

In patients with ischaemic left ventricular dysfunction and myocardial contractile reserve, coronary revascularization improves both functional capacity and prognosis of survival. The most cost-effective imaging techniques to detect reversible contractile function currently are stress echocardiography and nuclear
Table 3 Diagnostic accuracy for detection of myocardial viability in severely dyssynergic segments: (1) dobutamine-stress echocardiography vs F18-fluorodeoxyglucose-SPECT, (2) pulsed-wave Doppler tissue sampling vs F18-fluorodeoxyglucose-SPECT. Pulsed-wave Doppler tissue sampling shows an increased sensitivity (P<0.05) to dobutamine-stress echocardiography to detect myocardial viability. Data are presented as percentages with 95% confidence intervals

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Accuracy</th>
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<td>(2) Pulsed-wave Doppler tissue sampling vs F18-fluorodeoxyglucose-SPECT</td>
<td>87 (82–92)*</td>
<td>52 (44–59)</td>
<td>76 (62–82)</td>
<td>69 (62–75)</td>
<td>74 (67–80)</td>
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</table>

NPV = negative predictive value; PPV = positive predictive value; *P<0.005.

perfusion/metabolism imaging. Echocardiography has the advantage of widespread availability, but subjective evaluation remains a limitation[9]. Doppler tissue imaging provides quantitative data and therefore merits clinical evaluation for testing patients for viability. The pulsed-wave Doppler tissue sampling allows sampling of selected segments and we used this for measuring the velocities of six myocardial segments. We correlated subjective wall motion scores during dobutamine-stress echocardiography and quantitative data of pulsed-wave Doppler tissue sampling with F18-fluorodeoxyglucose-SPECT. This method has comparable accuracy for viability detection to positron emission tomography and was used as a reference[8].

The main finding of the present study is the higher sensitivity of pulsed-wave Doppler tissue sampling over dobutamine-stress echocardiography for myocardial viability detection when F18-fluorodeoxyglucose-SPECT is used as a reference. This finding is explained by the amplification effect of basal assessment by pulsed-wave Doppler tissue sampling, which is able to detect even small amounts of viable myocardium disseminated between the base and apex. However, pulsed-wave Doppler tissue sampling may overestimate the presence of myocardial viability. In segments with scar tissue, increased contraction velocity during low-dose dobutamine may occur due to a tethering effect of adjacent viable segments. Most of these observations are made in akinetic segments in the intraventricular septum. A possible way to avoid this would be a multi-sampling approach, in additional areas between the base and the apex or by using parasternal views (the latter allows assessing a limited number of segments). In contrast, an underestimation may be related to a lack of contractile function in severely dyssynergic areas, with preserved epicardial metabolic activity. These findings are consistent with higher myocardial integrity required for an inotropic response than for metabolic uptake. This was also shown by PET imaging where areas with a mismatch pattern of flow/metabolism by PET failed to improve after revascularization[1].

Potential advantages of using the long axis

Cumulative velocities obtained in apical views by pulsed-wave Doppler tissue sampling, in contrast to the equatorial velocities, represent the vectorial sum of contraction velocities of myocardial fibres between the base and apex. The importance of longitudinal contraction for the evaluation of left ventricular function was emphasized by Gibson et al.[12] using M-mode at the level of the mitral annulus in apical views. It was shown that longitudinal contraction contributes to half of the left ventricular ejection fraction and adds prognostic information for late cardiac events[7]. Also diastolic PS-DTS parameters are better investigated by the longitudinal approach[13,14]. Finally the use of apical views excludes virtually any global cardiac displacement, as the apex acts as a fixed reference point and the displacement of the cardiac base toward the apex was the result of only myocardial fibre contraction[15].

Respiratory effect on left ventricular function

Respiration affects more right than left ventricular dynamics. Garcia et al.[13] showed by averaging a sequence of five beats, usually encompassing a normal respiratory cycle, a minimal effect on left ventricular dynamics. In our study we also used the average of five consecutive beats.

Dobutamine infusion protocol

We used a low-dose dobutamine (5 and 10 μg · kg⁻¹ · min⁻¹, 5 min step) infusion protocol. As shown in a previous study, in the ‘classic’ low-dose stepwise protocol starting with 10 μg · kg⁻¹ · min⁻¹ for 3 min, sufficient dobutamine plasma concentrations might not be achieved to evaluate improved wall thickening in all patients[16]. In all patients a sufficient plasma
dobutamine concentration to evaluate improved wall thickening (80–90 ng . ml⁻¹) was achieved after a 6 min infusion period. We therefore assessed improved wall thickening after a 10 min dobutamine infusion.

**Comparison with previous Doppler tissue studies**

So far, few reports indicate the potential of Doppler tissue imaging and more particularly pulsed-wave Doppler tissue sampling, to detect myocardial viability[6]. Gorcsan et al[17] sampled a velocity profile by colour M-mode during dobutamine in the apical four-chamber view close to the mitral annulus. They demonstrated increased sensitivity for myocardial viability, compared to the same approach in the parasternal view. Traditional viability parameters were less sensitive than the basal longitudinal approach. Recently, the longitudinal approach using pulsed-wave Doppler tissue sampling was also used to detect myocardial ischaemia in the animal model[18]. After induction of ischaemia in pigs it was shown that myocardial contraction velocity was reduced using a single sample of pulsed-wave Doppler tissue sampling in apical views.

In our study peak ejection velocity of non-viable myocardium reproduced velocity values of abnormal myocardium found by Katz et al[19] and Yamada et al[20]. Most of our ejection velocity values remained below the cut-off of 12 cm . s⁻¹ as reported by Yamada et al[20] as typical of normal contracting myocardium. The severity of resting myocardial dyssnergy in our study may explain the low magnitude of velocity increase under dobutamine, while in normal myocardium a higher and earlier increase of ejection velocity was reported by Gorcsan et al[17].

**Study limitations**

Due to time limitations of the standard dobutamine-stress echocardiography protocol, especially at peak stress, we rejected a 16-segment approach. We were also not able to measure the equatorial contraction, due to Doppler angular dependence. Recent advances, e.g. anatomical M-mode, show potential for overcoming this latter limitation[21].

**Conclusion**

In patients with severe left ventricular dysfunction, longitudinal pulsed-wave Doppler tissue sampling provides quantitative information and was complementary to dobutamine-stress echocardiography for the assessment of myocardial viability.

**References**


