Dobutamine-Atropine Stress Echocardiography for the Detection of Coronary Artery Disease in Patients With Left Ventricular Hypertrophy
Importance of Chamber Size and Systolic Wall Stress

Steven C. Smart, MD; Thomas Knickelbine, MD; Fayaz Malik, MD; Kiran B. Sagar, MD

Background—Left ventricular hypertrophy is a heterogeneous disorder with distinct morphologies. Changes in wall thickness, left ventricular chamber diameter, and mass alter systolic wall stress of the left ventricle and may influence ischemic threshold. Thus, the goal of this study was to investigate the effect of the different patterns of left ventricular hypertrophy on the accuracy of dobutamine-atropine stress echocardiography.

Methods and Results—Three-hundred eighty-six patients underwent multistage dobutamine-atropine stress echocardiography and diagnostic angiography. Echocardiograms were measured for mean and relative wall thicknesses, chamber size, left ventricular mass, and end-systolic wall stress. The patterns of ventricular hypertrophy were concentric hypertrophy (increased wall thickness and mass), eccentric hypertrophy (normal wall thickness and increased mass), and concentric remodeling (increased wall thickness and normal mass). The overall sensitivity, specificity, and accuracy of dobutamine-atropine stress echocardiography for the detection of coronary artery disease were 85%, 87%, and 86%, respectively. Increased left ventricular mass index alone did not affect accuracy. Sensitivity was markedly reduced (36%) only in those with concentric remodeling. The univariate predictors of false-negative studies were single-vessel left circumflex disease, increased wall thickness, small chamber size, hyperdynamic ejection fraction, and left ventricular concentric remodeling. Multivariate predictors were concentric remodeling ($P < 0.0001; \text{odds ratio, 13.5}$), left ventricular ejection fraction $> 2 \text{SD above normal (} P < 0.0001)$, and single-vessel left circumflex disease ($P < 0.0007; \text{odds ratio, 7.6}$). Sensitivity was excellent in patients with small ventricles and normal wall thickness and in those with normal or large chambers regardless of wall thickness.

Conclusions—Dobutamine-atropine stress echocardiography is an accurate test in most patients with left ventricular hypertrophy, but it is insensitive in the small subset with concentric remodeling. (Circulation. 2000;101:258-263.)

Key Words: hypertrophy ■ echocardiography ■ coronary disease

Left ventricular (LV) hypertrophy has heterogeneous morphologies with variable changes in LV mass, volume, wall thickness, diameter, systolic wall stress, and coronary flow reserve.1-6 By definition, the adaptive variations in wall thickness and ventricular size result in different systolic meridional wall stress, which may alter the threshold for demand-based ischemia2 and may impair the capacity of dobutamine atroipine stress echocardiography to detect coronary artery disease.

LV hypertrophy has no influence on the accuracy of exercise stress echocardiography.7-8 However, the effect of LV hypertrophy on the accuracy of dobutamine-atropine stress echocardiography remains unclear, especially in relation to LV wall thickness, chamber diameter, and systolic meridional wall stress. In the present study, we postulated that LV morphology, specifically wall thickness/diameter, and systolic meridional wall stress significantly influence the accuracy of dobutamine-atropine stress echocardiography to detect coronary artery disease. The specific aim of the study was to determine the effect of LV mass, wall thickness, chamber size, and systolic meridional wall stress on the sensitivity and specificity of dobutamine-atropine stress echocardiography.

Methods

Patient Selection

Between July 1992 and June 1996, 386 patients with known or suspected coronary artery disease underwent both dobutamine-atropine stress echocardiography and diagnostic coronary angiography within 1 month of each other at the Milwaukee County Medical Complex. All patients gave informed consent. Exclusion criteria were recent myocardial infarction (<1 month), unstable angina, severe hypertension (blood pressure $> 220 \text{ mm Hg or diastolic}$)

Received April 27, 1999; revision received August 9, 1999; accepted August 26, 1999.
From the Division of Cardiology, Medical College of Wisconsin, Milwaukee.
Correspondence to Kiran B. Sagar, MD, Medical College of Wisconsin, Division of Cardiovascular Medicine, 9200 W Wisconsin Ave, Milwaukee, WI 53226.
© 2000 American Heart Association, Inc.
Circulation is available at http://www.circulationaha.org

258
pressure >120 mm Hg), or sustained ventricular tachycardia. Hypertension was blood pressure >160/90 mm Hg.

Dobutamine stress echocardiography, image acquisition, and analysis were performed according to previously published methods.9–11 LV septal thickness, posterior wall thickness, and chamber size were measured in the parasternal long axis at end diastole from the digitized images.12 Specular boundary echoes were excluded from the septum and posterior wall and were included in the LV diameter measurement.12 These 2-dimensional (2D) measurements were validated by correlation studies to M-mode measurements derived from the 2D parasternal long-axis view in a series of 25 patients. There were highly linear correlations between digitized 2D and M-mode measurements of wall thickness and LV diameter in diastole and systole, relative wall thickness, and LV mass. Mean wall thickness (MWT) was the average of septal and posterior wall thicknesses. End-diastolic relative wall thickness (RWT) was the ratio of (2*(MWT)) to LVID, where LVID is LV chamber size in end diastole. LV volumes and ejection fraction (LVEF) were obtained at end diastole and end systole at rest by use of the apical 4-chamber view and application of the modified Simpson’s rule method.13 LV mass was calculated by the method reported by Devereux and Reichek.14 LV wall stress was calculated at rest in systole as the average meridional stress with uniform wall thickness and homogeneous elasticity assumed as P(LVESD)/4h(1-h/LVESD), where LVESD is LV end-systolic diameter, P is LV pressure, and h is mean systolic wall thickness.2

To ensure standardization of measured values with a representative population at our institution, an age-matched series of 100 normal dobutamine echocardiograms were measured in 242 patients. The sensitivity and specificity of wall motion abnormalities were used to compare the relationships of sensitivity, specificity, and wall stress (SigmaPlot 4.0, SPSS, Inc). Stepwise multiple logistic regression analysis was used to identify independent causes of false-negative and false-positive results. A 2-tailed value of P<0.05 was significant.

### Results

#### Patient Data

The 386 patients enrolled in the study had a mean age of 61±12 years. There were 133 women and 253 men. One hundred twenty patients were treated with β-adrenergic blocking agents, 127 with calcium channel blockers, and 169 with nitrates or other vasodilators. Hypertension was documented in 242 patients.

#### Dobutamine Infusion

The mean peak dose of dobutamine was 26±12 μg·kg⁻¹·min⁻¹. Atropine (0.2 to 2.0 mg) was used in 176 patients (46%). Resting heart rate, systolic blood pressure, and rate-pressure product were 71±13 bpm, 134±23 mm Hg, and 9563±418 mm Hg/min, respectively. Mean peak heart rate, systolic blood pressure, and rate-pressure product increased to 127±17 bpm, 142±37 mm Hg, and 184±5103 mm Hg/min, respectively. End points for peak dose were heart rate >120 bpm in 310 patients, severe anginal chest pain in 18, maximum dose in 32, nonsustained ventricular tachycardia (5 to 8 beat runs) in 7, hypotension in 6, hypertension in 3, multiple inducible wall motion abnormalities at a submaximal heart rate in 7, and severe nausea or vomiting in 3.

#### Coronary Angiography

Coronary angiography detected significant coronary artery disease in 280 patients (73%). There were 169 patients with multivessel coronary artery disease and 111 with single-vessel disease. Of these 111 patients, 87 had stenosis ≥70% and 24 had stenosis between 50% and 69%. Of the patients with single-vessel disease, 38 had left anterior descending disease, 21 had left circumflex disease, and 52 had right coronary artery disease.

#### Dobutamine Echocardiographic Data

There were 122 normal and 264 abnormal stress echocardiograms. The sensitivity and specificity of wall motion abnor-

---

### TABLE 1. Mean±SD of Measured Values in 100 Normal Dobutamine Echocardiograms

<table>
<thead>
<tr>
<th></th>
<th>Diastolic MWT, cm</th>
<th>Systolic MWT, cm</th>
<th>RWT, cm</th>
<th>LV Mass, g</th>
<th>Mass Index (BSA), g/m²</th>
<th>LVID, cm</th>
<th>LVESD, cm</th>
<th>SV, mL</th>
<th>Systolic Circumferential Wall Stress, dyne/cm²</th>
<th>Systolic Meridional Wall Stress, dyne/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients (n=100)</td>
<td>0.8±0.1</td>
<td>1.2±0.1</td>
<td>0.37±0.06</td>
<td>148±37</td>
<td>80±20</td>
<td>4.6±0.5</td>
<td>3.3±0.5</td>
<td>52±16</td>
<td>198±48</td>
<td>72±18</td>
</tr>
<tr>
<td>Men (n=50)</td>
<td>0.9±0.1</td>
<td>1.2±0.1</td>
<td>0.36±0.06</td>
<td>164±33*</td>
<td>82±17</td>
<td>4.8±0.4</td>
<td>3.4±0.4</td>
<td>59±16</td>
<td>204±51</td>
<td>74±19</td>
</tr>
<tr>
<td>Women (n=50)</td>
<td>0.8±0.1</td>
<td>1.1±0.1</td>
<td>0.37±0.06</td>
<td>137±35</td>
<td>78±22</td>
<td>4.5±0.5</td>
<td>3.2±0.4</td>
<td>54±19</td>
<td>193±44</td>
<td>71±17</td>
</tr>
</tbody>
</table>

BSA indicates body surface area; LVSD, systolic LV diameter; and SV, stroke volume.

P<0.0001 vs women.
malities for detecting coronary artery disease were 85% (238 of 280) and 87% (92 of 106), respectively. The positive predictive values of fixed resting and induced wall motion abnormalities were 97% (60 of 62) and 94% (178 of 190), respectively. The negative predictive value of a normal dobutamine-atropine stress echocardiogram or sustained improvement in all vascular territories was 69% (92 of 134). Sensitivity was higher \( P < 0.05 \) for multivessel disease (88%, 149 of 169) than single-vessel disease (80%, 89 of 111) and for single-vessel disease and \( \geq 70\% \) stenosis (87%, 76 of 87) than single-vessel disease and 50% to 69% stenosis (54%, 13 of 24). Sensitivity was 85% (44 of 52) in single-vessel right coronary artery disease, 84% (32 of 38) in single-vessel left anterior descending disease, but only 62% (13 of 21, \( P < 0.05 \)) in single-vessel left circumflex disease. False-positive studies occurred only in patients with isolated wall motion abnormalities in the right coronary or left circumflex vascular territories (14% [14 of 98] versus 0% [0 of 35] for left anterior descending only and 0% [0 of 119] for multiple wall motion abnormalities, \( P = 0.01 \)). Sensitivity was higher \( P < 0.001 \) in patients with abnormal resting wall motion (98% [61 of 62] versus 81% [177 of 218] in patients with normal resting wall motion), but specificity was similar (83% [10 of 12] versus 87% [82 of 94], respectively, \( P = \text{NS} \)).

**Echocardiographic Measurements**

The normal database (Table 1) revealed that the criterion for increased wall thickness was \( \geq 1.1 \) cm for men and women. A small chamber in diastole was \( \leq 4.1 \) cm in men and \( \leq 3.9 \) cm in women. A dilated chamber in diastole was \( \geq 5.8 \) cm in men and \( \geq 5.5 \) cm in women. Low and high LVEFs were \(< 45\% \) and \(> 67\% \), respectively, in both men and women.

**Effects of Echocardiograms and Clinical Findings on Accuracy in Normal Resting Wall Motion**

In the 312 patients without resting wall motion abnormalities, LV hypertrophy was present in 152 patients (Figure 1): concentric hypertrophy in 93, eccentric hypertrophy in 14, and concentric remodeling in 45. Table 2 outlines the echocardiographic measurements and clinical data for the different types of LV hypertrophy, normal left ventricles, small left ventricles with normal wall thickness, and resting wall motion abnormalities. Hypertension and LV mass did not alter the accuracy of dobutamine-atropine stress echocardiography for detection of coronary artery disease. In the 194 patients with hypertension, sensitivity and specificity were 80% (110 of 138) and 84% (47 of 56), respectively. In the 118 normotensive patients, sensitivity and specificity were similar at 84% (67 of 80) and 92% (35 of 38). In the 82 patients with increased LV mass index, sensitivity and specificity were 87% (48 of 55) and 85% (23 of 27). In the 230 patients with normal mass, sensitivity and specificity were similar at 79% (129 of 163) and 88% (59 of 67).

Figure 2 shows the effects of wall thickness, chamber size, and relative wall thickness on accuracy in the detection of coronary artery disease. Increased wall thickness, small chamber size, and high relative wall thickness reduced sensitivity without altering specificity \( P < 0.05 \).

**Multivariate Analysis of Data**

The univariate causes of false-negative studies were increased wall thickness, small chamber size, concentric remodeling, increased relative wall thickness, low global rest-
ing LV wall stress, small diastolic volume, high LVEF, single-vessel coronary artery disease, and single-vessel left circumflex coronary artery disease. The multivariate predictors of false-negative studies were concentric remodeling (P < 0.000001) and single-vessel coronary artery disease (P = 0.0007). The univariate causes of false-positive studies were induced wall motion abnormalities, wall motion abnormalities isolated in a single vascular territory, and isolated wall motion abnormalities of the basal inferior and lateral walls. The only independent cause of false-positive studies

<table>
<thead>
<tr>
<th>TABLE 2. Echocardiographic Measurements and Clinical Data According to Hypertrophy Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric Hypertrophy (n = 93)</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>Wall thickness, diastole, cm</td>
</tr>
<tr>
<td>Wall thickness, systole, cm</td>
</tr>
<tr>
<td>LV diameter, diastole, cm</td>
</tr>
<tr>
<td>LV diameter, systole, cm</td>
</tr>
<tr>
<td>RWT</td>
</tr>
<tr>
<td>LV mass index (BSA), g/m^2</td>
</tr>
<tr>
<td>Meridional wall stress, dyne/cm^2</td>
</tr>
<tr>
<td>Circumferential wall stress, dyne/cm^2</td>
</tr>
<tr>
<td>LV end-diastolic volume, mL</td>
</tr>
<tr>
<td>Stroke volume, mL</td>
</tr>
<tr>
<td>LVEF, %</td>
</tr>
<tr>
<td>Age, y</td>
</tr>
<tr>
<td>Female sex, % (n)</td>
</tr>
<tr>
<td>Hypertension, % (n)</td>
</tr>
<tr>
<td>β-Blocker, % (n)</td>
</tr>
<tr>
<td>Peak HR, bpm</td>
</tr>
<tr>
<td>Peak SBP, mm Hg</td>
</tr>
</tbody>
</table>

WT indicates wall thickness; BSA, body surface area; HR, heart rate; and SBP, systolic blood pressure. Values are mean ± SD.

*P < 0.05 vs concentric hypertrophy; †P < 0.05 vs normal mass and wall thickness; ‡P < 0.05 vs eccentric hypertrophy; §P < 0.05 vs small LV chamber and normal WT.

Figure 2. Sensitivity and specificity according to LV diameter (LVD), wall thickness (WT), and RWT in patients with normal resting wall motion. >2SD indicates >2 SD above normal mean; <2SD, <2 SD below normal mean. *P < 0.01 vs normal or low wall thickness; †P < 0.01 vs normal or high LV diameter; ‡P < 0.01 vs normal or low RWT.

Figure 3. Sensitivity and specificity in patients with normal resting wall motion and normal LV diameter (LVD) and wall thickness (WT), normal wall thickness with small diameter, concentric remodeling, concentric hypertrophy, and eccentric hypertrophy in patients. *P < 0.01 vs all other subsets.
Intraobserver variability of echocardiographic measurements was minimal in a representative subset of 60 patients, including 40 patients with and 20 patients without coronary artery disease. The interpretations of the 2 investigators regarding the presence or absence of wall motion abnormalities agreed in 92% (55 of 60). Intraobserver variability was assessed by 1 investigator. The 2 readings were concordant regarding the presence or absence of wall motion abnormalities in 97% (58 of 60).

Intraobserver variability of echocardiographic measurements was assessed in the same cohort of patients. The mean variations in chamber size and wall thickness were 0.94, 0, and 0.99±0.004, respectively. These values for chamber size were 0.96, 0, and 1.00±0.004, respectively.

**Discussion**

This study shows that patients with small LV chamber size and increased wall thickness, the pattern called concentric remodeling, exhibit an excessively high number of false-negative studies in the presence of significant angiographic coronary stenoses. Concentric remodeling was the strongest univariate and multivariate predictor of false-negative studies. In contrast, sensitivity was preserved in patients with small chamber size and normal wall thickness, concentric and eccentric hypertrophy. The presence of hypertension or increased LV mass index alone did not affect accuracy. Although adjunctive measures, such as the addition of intravenous atropine to augment heart rate response in patients taking β-blocker therapy, have been shown to overcome decreases in sensitivity during dobutamine stress echocardiography, LV morphological patterns may represent the most important absolute limitation of its detection of coronary stenoses.

Ganau et al reported that LV hypertrophy occurred in 3 morphological patterns in a series of 165 hypertensive patients: increased ventricular mass and wall thickness as typical concentric hypertrophy, increased mass and normal wall thickness as eccentric hypertrophy, and increased wall thickness and normal LV mass as concentric remodeling. Chamber size is normal or large in concentric hypertrophy, large in eccentric hypertrophy, and small in concentric remodeling. These more direct definitions of specific patterns of hypertrophy may be needed in evaluations of the accuracy of stress echocardiography. Marwick et al reported that the accuracy of exercise echocardiography is not impaired in patients with LV hypertrophy. The definition of hypertrophy used, however, was increased LV mass index. The present study is concordant with these findings in that an absolute increase in LV mass index did not affect accuracy. However, our study demonstrates a significant reduction in sensitivity of dobutamine stress echocardiography in a small subset of patients with LV hypertrophy, concentric remodeling. Marwick et al reported that increased wall thickness (defined as wall thickness >1.2 mm) did not alter the sensitivity (73% versus 72%) or specificity (94% versus 83%) of dobutamine stress echocardiography. However, chamber size and LV mass were not documented, the peak heart rate was only 109±25 bpm, and atropine was not used. In the present study, sensitivity was decreased most prominently in patients with the combination of increased wall thickness and small LV chamber in concentric remodeling. Small chamber size in the absence of increased wall thickness was not associated with false-negative studies. In the present study, atropine was frequently used (44% of patients), the peak heart rate was higher (128±17 bpm), and the percentage of patients with increased wall thickness was higher (48%) than Marwick et al used.

The sensitivity of dobutamine stress echocardiography for detection of coronary artery disease has been shown to range from 76% to 96%. Previous studies have identified submaximal stress, single-vessel disease, distal coronary artery disease, female sex, and β-adrenergic blocker therapy as potential causes of false-negative studies. Specificity of dobutamine stress echocardiography has ranged from 60% to 95%. Inadequate endocardial visualization, myocardial ischemia caused by microvascular disease, and wall motion abnormalities unrelated to coronary artery disease (cardiomyopathy or left bundle-branch block) have been hypothesized to cause false-positive studies. Bach et al reported that the primary causes of false-positive dobutamine echocardiogra-
phy were female sex, wall motion abnormalities of the basal segments of the posterior circulation, and intermediate coronary stenoses ≥40%; however, fewer women were included in the present study. Patients with concentric remodeling commonly have hypertension and a high probability of microvascular coronary artery disease and impaired coronary flow reserve. In our study patients, neither concentric remodeling nor hypertension was a cause of false-positive results. These observations suggest that although microvascular coronary disease can lead to angina in patients with normal coronary arteries, these patients do not manifest significant clinically detectable wall motion abnormalities during the peak stress phase of dobutamine-atropine stress echocardiography.

One hypothesis to explain why small chamber size and increased wall thickness caused false-negative studies may be that these patients have an increased threshold for demand ischemia and induced wall motion abnormalities. A consequence of the marked increase in myocardial wall thickness and decrease in LV chamber size is reduced systolic wall stress and myocardial displacement during stress. The results of the present study demonstrate that reduced systolic wall stress causes sensitivity to plummet. Furthermore, hyperdynamic wall motion is common in these patients. Thus, ischemic segments that become hypokinetic or akinetic during stress may remain visually undetected because of minimal excursion distances and “tethering” from adjacent hyperdynamic segments.

Overestimation of noncritical stenosis by the caliper technique may contribute to reduced sensitivity; however, only 24 of 111 (22%) of patients with single-vessel disease in the present study had a stenosis from 50% to 69%. Patients with intermediate coronary stenosis (40% to 70%) often do not have impaired coronary flow reserve. Sensitivity may be reduced in these patients, but this factor did not account for the reduced sensitivity in concentric remodeling patients. Therefore, our conclusions regarding the sensitivity of dobutamine-atropine stress echocardiography remain valid.

Sharp et al. reported a sensitivity of 83% and specificity of 71% in patients with dilated cardiomyopathy. Sensitivity of dobutamine stress echocardiography for detection of triple-, double-, and single-vessel disease was 100%, 83%, and 69% respectively. In our study, in patients with concentric remodeling (LVEF, 61%), sensitivity was 36% and specificity was 89% (Figure 3). In the group with eccentric hypertrophy and reduced LVEF, specificity was significantly reduced, similar to the results reported by Sharp et al. In conclusion, dobutamine-atropine stress echocardiography may not be the ideal test for the small subset of patients with small LV chamber, increased wall thickness, and high relative wall thickness, a pattern recognized as concentric remodeling, especially the extreme cases. In contrast, dobutamine-atropine stress echocardiography remains an accurate diagnostic test in patients with eccentric hypertrophy, those with typical concentric hypertrophy, and even those with small chambers but normal wall thickness.

References


Dobutamine-Atropine Stress Echocardiography for the Detection of Coronary Artery Disease in Patients With Left Ventricular Hypertrophy: Importance of Chamber Size and Systolic Wall Stress
Steven C. Smart, Thomas Knickelbine, Fayaz Malik and Kiran B. Sagar

_Circulation_. 2000;101:258-263
doi: 10.1161/01.CIR.101.3.258

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2000 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/101/3/258

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation_ is online at:
http://circ.ahajournals.org//subscriptions/