Stress echocardiography with transesophageal atrial pacing: preliminary report of a new method for detection of ischemic wall motion abnormalities

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ABSTRACT We performed two-dimensional echocardiography in 19 patients with significant coronary artery disease and in six normal volunteers at rest and during transesophageal atrial pacing. Technically adequate resting echocardiograms were obtained in 18 of the 19 patients and in all six normal volunteers. In two subjects, atrial capture was not possible, and in one subject, discomfort from the pacing at the beginning of the study precluded its completion. In all subjects (n = 21) who completed the protocol satisfactory two-dimensional echocardiograms were obtained during pacing. Wall motion was normal at rest and during atrial pacing in five normal volunteers. New transient wall motion abnormalities developed in 13 of the 16 patients during pacing. Twelve of the 13 patients had significant coronary lesions in the coronary arteries supplying the abnormal wall segment. Only three of the patients developed significant ST segment depression during pacing. We conclude that (1) stress echocardiography with transesophageal atrial pacing is safe and practical and can be used in patients who cannot perform dynamic exercise, (2) this technique can detect ischemic segmental wall motion abnormalities corresponding to the distribution of coronary arterial obstruction, and (3) the technique provides high-quality echocardiographic images during stress and thus may expand the usefulness of resting two-dimensional echocardiography in patients who have ischemic heart disease.


REVERSIBLE segmental left ventricular wall motion abnormalities due to transient myocardial ischemia are a hallmark of atherosclerotic coronary heart disease. While two-dimensional echocardiography has proven very useful in the detection of fixed wall motion abnormalities that occur after myocardial infarction1, 2 or during coronary artery spasm,3 considerably less success has been achieved in evaluating transient wall motion abnormalities produced by such interventions as bicycle exercise. This study was undertaken to determine if transesophageal atrial pacing could serve as a suitable, minimally invasive, provocative intervention to induce transient myocardial ischemia without interfering with the quality of the two-dimensional echocardiograms obtained.

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Methods

Patient population. Nineteen patients, each of whom had significant coronary artery stenosis (greater than or equal to 50% luminal obstruction) at the time of coronary angiographic examination, were selected for study. All gave informed consent to a protocol approved by the Human Studies Committee of the Medical College of Wisconsin. All patients had previously experienced chest pain that was considered to be due to either angina pectoris (16 patients), myocardial infarction (seven patients), or both. Seventeen of the patients were men and two were women and their average age was 58 years (range 46 to 69). Six normal volunteers, all physicians in training, were also studied. Five were men and one was a woman and their average age was 29 years (range 27 to 32).

Echocardiographic technique. Two-dimensional echocardiograms were obtained within 14 days after cardiac catheterization at rest and during and after transesophageal atrial pacing with a commercially available, wide-angle, phased-array ultrasoundoscope (Diasonics V3400 or Irex System IIIb). The transducer was held by hand on the patient’s chest. Real-time images were recorded on videotape for later replay and analysis. In the initial studies in patients at rest, views from all available acoustic windows were recorded. During pacing new areas of abnormal wall motion were identified on multiple views by rapidly manipulating the ultrasound transducer through various positions. Having established an optimal position for observation of abnormal wall motion, often the apical four-chamber or two-chamber view, the transducer was held stationary throughout the remainder of the study and the recovery period.
The videotapes were analyzed by two observers who reached a consensus interpretation for each study. Segmental anatomy and wall motion were assessed in a qualitative manner as previously reported. Motion of the various ventricular segments was described as normal, hypokinetic, akinetic, or dyskinetic. The observers were unaware of the results of cardiac catheterization but did know which subjects did not undergo catheterization. Videotapes were later analyzed a second time by one of the two observers who had no knowledge of the initial interpretation or which of the subjects had undergone cardiac catheterization.

Pacing protocol. A bipolar temporary silicone rubber endocardial pacing lead (Medtronic Model No. 5824) was placed through the nares into the esophagus of each subject to a distance of 30 to 35 cm. The electrode position was confirmed by bipolar electrocardiographic recording of an atrial electrogram. A baseline 12-lead electrocardiogram was then obtained. The esophageal lead was then connected to the output of an esophageal pacing system (Stat-Pace System, kindly provided by Secor, Inc., Fort Worth, TX). The pulse width was set at 10 msec and the current was adjusted until atrial capture was achieved. Capture was assessed by continuous electrocardiographic monitoring. During continuous two-dimensional echocardiography, pacing was begun at 100 beats/min and continued for 1 min. The pacing rate was then increased to the rate at which a maximum 1:1 atrioventricular conduction rate was observed or to the age-predicted maximum heart rate and maintained there until an end point was reached. End points were (1) the development of chest pain or (2) the development of new or worsening wall motion abnormalities evident on the echocardiogram. Since the pacing spike obscured the ST segment, an electrocardiogram at the peak pacing rate was obtained by turning off the pacemaker transiently to record two to three QRS complexes for each lead with the use of a three-channel electrocardiographic recorder. Only limb leads were monitored because the echocardiographic examination interfered with the recording of precordial leads.

Cardiac catheterization and cineangiography. Cardiac catheterization by the Sones or Judkins technique was performed in all patients within 2 weeks before the pacing study. The coronary arteries were visualized in multiple projections. Biplane left ventriculography was performed in the right and left anterior oblique projections. Cardiac catheterization data were analyzed without knowledge of the echocardiographic findings.

Treadmill testing. Treadmill exercise testing by the Bruce protocol was performed by 11 of the 19 patients and by all six normal volunteers within 2 weeks of the pacing study. The exercise electrocardiogram was considered positive if a normal baseline ST segment exhibited horizontal or downsloping depression greater than 1 mm 80 msec beyond the J point during or immediately after exercise.

Results

Technically adequate resting echocardiograms were obtained in 18 of the 19 patients (95%) and in all six normal volunteers. Eight patients had areas of abnormal wall motion at rest on their two-dimensional echocardiograms, which corresponded to similar segments of abnormal motion on their left ventriculograms. Of the 21 subjects who completed the protocol, all had adequate echocardiograms during pacing. Pacing could not be accomplished in one patient and one normal subject due to inability to capture the atrium. One patient experienced an unacceptable level of discomfort during esophageal pacing and the study could not be completed. The normal volunteers reported that the sensation due to transesophageal atrial pacing was disagreeable but not intolerable.

No new wall motion abnormalities were identified during atrial pacing in any of the five normal volunteers.

Of the 16 patients who completed the pacing protocol with adequate echocardiograms, transient wall motion abnormalities developed during pacing in 13. Examples of the segmental asynergy that occurred during pacing are shown in figures 1 and 2. It should be noted that major deterioration occurs when still-frame videotapes are photographed. Wall motion was analyzed in real time in this study, not from still frames. The results of the pacing study along with cardiac catheterization and stress test data are summarized in table 1. All 13 patients in whom transient wall motion abnormalities were observed had significant coronary artery disease. Each of twelve of the patients had a significant lesion in the coronary artery supplying the abnormal wall segment identified during pacing. In one patient (No. 1) the wall motion abnormality did not correspond to the territory of the significant coronary arterial obstruction. The explanation for this is unclear, but the left anterior descending artery in this patient was small, the right coronary artery was large and dominant, and the right coronary artery did provide some collateral flow to the region.

Three patients who had significant coronary artery disease did not develop wall motion abnormalities with pacing. One patient (No. 9) had previously undergone three-vessel coronary artery bypass grafting of all significant coronary lesions. All grafts were patent and the ventriculogram was normal. Two other patients (Nos. 18 and 19) who did not have pacing-induced wall motion abnormalities did have significant coronary arterial stenoses and their pacing study data represented false-negative results. No ST segment changes or symptoms were produced by pacing to the maximum 1:1 atrioventricular conduction rate.

The overall sensitivity for the detection of significant coronary artery disease in this selected group was 13/15 or 87% (excluding patient No. 1, as mentioned previously). The sensitivity of the test for identifying the territory of coronary blood flow affected was 12/13 or 92%. The specificity for detecting coronary artery disease (true negatives/true negatives + false positives) was 5/5 or 100%.

Of the 18 patients in whom capture of the atrium was accomplished, nine developed chest pain during pacing. In one patient (No. 12), pain developed immediately after the start of pacing and was qualitatively
Incremental atrial pacing during cineangiographic and radionuclide left ventriculography has been used to produce myocardial ischemia and segmental asyn-
ergy.6-9 When atrial pacing results in myocardial ischemia, electrocardiographic changes similar to those seen with isotonic exercise can result.10-12 The sensitiv-
ity of such changes for identifying patients with coronary artery disease may be low compared with that of standard treadmill exercise testing due to absence of effect of atrial pacing on blood pressure and sympathetic tone.10

Hemodynamic studies in which atrial pacing is used have demonstrated the ability of this maneuver to increase the oxygen needs of the heart on a readily reversible basis without augmentation of blood pressure or cardiac output.13-15 Myocardial lactate production (an index of myocardial ischemia) is increased during atrial pacing in patients with angina.16

different from his anginal pain; the other eight patients who developed chest pain had discomfort indistinguishable from their anginal pain.

Significant ST depression was noted in three of the 14 patients in whom ST segments were observed during pacing. The location of the ST changes corre-
sponded to the location of the abnormal wall motion in all three cases. All 11 patients who performed treadmill testing had a positive stress test. Of these 11 patients, nine had a positive pacing study.

None of the normal volunteers developed ST seg-
ment changes during either treadmill stress testing or atrial pacing. Repeat interpretation of the two-dimen-
sional echocardiograms showed two discrepancies from the original interpretation; one showed abnormal wall motion not noted on the original interpretation and another showed normal motion in an area previously labeled abnormal.
Several studies have reported on the use of cardiac pacing with a transesophageal lead.\textsuperscript{17-21} Initial work on ventricular pacing in dogs was not encouraging because of the large anteroposterior diameter of the chest of the dog and great distance of the esophagus from the heart.\textsuperscript{17} The first report of transesophageal atrial pacing involved the treatment of patients with tachyarrhythmias and atrial capture was achieved in 17 of the 22 patients studied.\textsuperscript{20} The procedure has proven to be safe, as assessed by necropsy in animal preparations.\textsuperscript{17, 19} Esophagoscopy in patients has revealed evidence of pressure necrosis typical of any form of esophageal intubation, but there has been no evidence of coagulative necrosis resulting from the electric current or perforation or of other significant damage.\textsuperscript{20} Patient discomfort (pain or muscular stimulation) has been noted when high pacing thresholds and unipolar electrodes with an indifferent sternal electrode are used,\textsuperscript{19} but these problems are diminished by the use of a bipolar electrode.\textsuperscript{18, 20}

Echocardiography can noninvasively visualize the effects of acute and chronic ischemia on the left ventricle. Numerous studies have attempted to combine echocardiographic examination with some form of dynamic exercise.\textsuperscript{4, 22-28} The initial studies used M mode echocardiography. Mason et al.\textsuperscript{26} used supine bicycling as the dynamic exercise and they were able to obtain adequate echocardiograms during exercise in only 45% of their subjects. Crawford et al.,\textsuperscript{25} who used upright bicycle exercise, obtained adequate echocardiograms in only 44% of their subjects. They also noted that, in order to achieve adequate studies, beats recorded during the same phase of respiration as during the resting study had to be used. Sugishita and Koseki\textsuperscript{27} were able to record adequate M mode echocardiograms during supine bicycle exercise in 83% of subjects with adequate resting studies. They noted that with high levels of exercise, however, hyperventilation precluded adequate M mode echocardiographic examination.

Two-dimensional echocardiography provides improved visual orientation for the detection of regional

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**TABLE 1**

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Maximum heart rate (bpm)</th>
<th>ST depression</th>
<th>Abnormal wall motion on transesophageal pacing echocardiography during pacing</th>
<th>Angiographic data</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Symptom</td>
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<tr>
<td>1</td>
<td>46</td>
<td>M</td>
<td>150</td>
<td>1 mm</td>
<td>Apex and septum akinetic</td>
<td>Chest pain</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>M</td>
<td>120</td>
<td>None</td>
<td>Septum dyskinetic</td>
<td>Chest pain</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>M</td>
<td>130</td>
<td>None</td>
<td>Lateral wall hypokinetic</td>
<td>Chest pain</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>M</td>
<td>100</td>
<td>&lt; 1 mm</td>
<td>Posterior wall hypokinetic</td>
<td>Chest pain</td>
</tr>
<tr>
<td>5</td>
<td>67</td>
<td>M</td>
<td>120</td>
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<tr>
<td>6</td>
<td>63</td>
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<td>7</td>
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<td>M</td>
<td>160</td>
<td>None</td>
<td>Septum hypokinetic</td>
<td>Chest pain</td>
</tr>
<tr>
<td>8</td>
<td>62</td>
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<tr>
<td>10</td>
<td>58</td>
<td>M</td>
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<td>1 mm</td>
<td>Anteroapical wall hypokinetic</td>
<td>Chest pain</td>
</tr>
<tr>
<td>11</td>
<td>67</td>
<td>M</td>
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<tr>
<td>12</td>
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<td>None</td>
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<td>13</td>
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<tr>
<td>14</td>
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</tr>
<tr>
<td>15</td>
<td>53</td>
<td>M</td>
<td>Unable to capture</td>
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<td>Not done</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>55</td>
<td>M</td>
<td>120</td>
<td>Not done</td>
<td>Apex dyskinetic</td>
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</tr>
<tr>
<td>17</td>
<td>69</td>
<td>F</td>
<td>160</td>
<td>Not done</td>
<td>Anteroapical wall hypokinetic</td>
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<td>F</td>
<td>160</td>
<td>Not done</td>
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<td>None</td>
</tr>
<tr>
<td>19</td>
<td>49</td>
<td>M</td>
<td>140</td>
<td>Not done</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

LAD = left anterior descending coronary artery; LCX = left circumflex coronary artery; RCA = right coronary artery.

\textsuperscript{A}All three grafted and patent.

\textsuperscript{B}Grafts to first diagonal and LAD normal; grafts to LCX and RCA occluded.
wall motion abnormalities than is possible with the "ice pick" view of the M mode echocardiogram. Wann et al., using supine bicycle exercise, demonstrated areas of reversible segmental wall motion abnormalities in areas supplied by significantly stenosed coronary arteries identified on cardiac catheterization. Of note, however, is that in only 71% of their subjects were they able to obtain adequate echocardiographic studies during exercise. In a study of normal volunteers Zwehl et al. also obtained adequate exercise echocardiograms in 71%. They emphasized the problem of hyperventilation, which limits definition of the echocardiogram. Maurer and Nanda used two-dimensional echocardiography performed immediately after treadmill stress testing rather than during exercise to reduce interference due to chest wall motion and hyperventilation and obtained technically adequate examinations in 85% of subjects. A 70% sensitivity for the detection of coronary artery disease (in patients without prior myocardial infarction) was found. They also noted an excellent correlation of their results with those of studies of thallium perfusion during exercise. Using a similar approach Limacher et al. found a sensitivity of 91% for postexercise two-dimensional echocardiography (based on an abnormal ejection fraction response and/or segmental dyskinesia).

In our study, we were able to obtain adequate stress echocardiograms in all patients in whom an acceptable baseline study was possible. Problems with hyperventilation or chest wall motion were not encountered. The pacing was well tolerated by all but one patient. Importantly, the technique is not limited by physical disability, motivation, or poor physical conditioning of the patient, any of which may severely limit or preclude the performance of dynamic exercise. In addition, as has been previously emphasized, pacing may be safer than exercise or pharmacologic stress since it can be terminated promptly at the development of ischemia. It should be obvious, however, that atrial pacing does not give information about exercise capacity and blood pressure response, that the maximum heart rate generated is limited, and that other complex physiologic changes present during exercise are not simulated.

Stress echocardiography with transesophageal atrial pacing was highly sensitive (87%) in identifying patients who had significant coronary artery disease. Only one patient with patent bypasses of all significant coronary stenoses had no wall motion abnormalities induced by pacing. The procedure was also quite successful in locating the region of diminished flow, correctly identifying it 92% of the time. It should be emphasized that the patients studied were selected because of the presence of coronary artery disease at cardiac catheterization and the specificity of stress echocardiography with pacing in detecting coronary disease was addressed in this study with the use of only a small number of normal volunteers. Of interest is that the combination of transvenous atrial pacing and radionuclide ventriculographic imaging for detecting wall motion abnormality has been reported to be 100% specific in identifying patients with coronary artery disease.

Intraobserver variability was noted in two of the 23 cases analyzed a second time. Variability should be less if quantitative analysis is used and the use of endless-loop computer video displays that allow slowing of the frame rate and the display of the same images repeatedly may enable more accurate and precise analysis of wall motion during pacing.

We noted ST depression greater than or equal to 1 mm during the pacing protocol in only three patients. Ten other patients who exhibited reversible segmental wall motion abnormalities with atrial pacing did not develop significant ST depression. This is probably
related to the fact that the precordial leads were not monitored, but it has previously been noted that profound alterations in myocardial contractile function may occur before the appearance of ST segment changes.\textsuperscript{34}

We conclude that stress echocardiography with transesophageal atrial pacing can detect ischemic segmental wall motion abnormalities in areas supplied by stenosed coronary arteries. This technique appears to be safe and practical and not only expands the usefulness of resting two-dimensional echocardiography but allows a minimally invasive stressful intervention to be applied to patients who cannot perform dynamic exercise. Before it can be recommended as a screening examination, however, further work is needed to validate its specificity as well as to compare its predictive accuracy with that of other modalities that detect coronary artery disease.

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