Supine Bicycle Versus Post–Treadmill Exercise Echocardiography in the Detection of Myocardial Ischemia: A Randomized Single-Blind Crossover Trial

Shamim M. Badruddin, MD, Anwar Ahmad, MD, Judith Mickelson, MD, FACC, John Abukhalil, RT, William L. Winters, MD, MACC, Sherif F. Nagueh, MD, FACC, William A. Zoghbi, MD, FACC
Houston, Texas

OBJECTIVES We sought to determine the comparative accuracy of supine bicycle exercise echocardiography (SBE) and posttreadmill exercise echocardiography (TME) in detecting myocardial ischemia in patients with known or suspected coronary artery disease (CAD).

BACKGROUND Supine bicycle echocardiography and TME have been used for evaluation of CAD. However, the comparative accuracy of these modalities in the detection of ischemia in the same patients is not known.

METHODS Seventy-four patients (age 59 ± 9 years [mean ± SD]) referred for evaluation of coronary disease underwent SBE (starting at 25 to 50 W with 25-W increment every 3 min) and post-TME (Bruce protocol) in a random sequence. Digitized images at baseline and maximal exercise were interpreted in a random and blinded fashion.

RESULTS Maximal heart rate was higher during TME, whereas systolic blood pressure was higher during SBE, resulting in a similar double product. At quantitative angiography (n = 67), 57 patients had coronary stenosis (>50%). During SBE, ischemia was detected in 47 patients compared with 38 patients by TME (p < 0.001). Wall motion score index at maximal exercise was higher with SBE than with TME (1.48 ± 0.51 vs. 1.38 ± 0.43; p < 0.001). The extent of myocardial ischemia (number of ischemic segments) was higher during SBE compared with TME (3.3 ± 3.4 vs. 2.3 ± 2.9 segments; p = 0.004), whereas severity of abnormal wall motion was similar. The sensitivity of SBE and TME for CAD was 82% and 75% with a specificity of 80% and 90%, respectively. Image quality was similar with both techniques. Patients and sonographers favored SBE over TME.

CONCLUSIONS During SBE and TME exercise, patients achieve a similar double product. During SBE, however, the detection of ischemia is more frequent and more extensive which, along with patient and sonographer preference, makes supine bicycle exercise a valuable stress echocardiographic modality. (J Am Coll Cardiol 1999;33:1485–90) © 1999 by the American College of Cardiology

Exercise echocardiography is rapidly gaining popularity as a useful diagnostic test for the evaluation of coronary artery disease (CAD). The underlying premise with stress echocardiography is that the induction of ischemia in patients with CAD is manifested by a transient wall motion abnormality detected with echocardiographic imaging. Post–treadmill exercise echocardiography (TME) imaging is the most frequently applied exercise echocardiographic modality where images are acquired immediately after exercise (1–4). This approach relies on imaging within a short time after the stress, a period when ischemia is resolving, which may affect the sensitivity of the test for detecting ischemia.

In comparison, supine bicycle exercise echocardiography (SBE) (5) has the advantage of imaging during stress and at peak exercise. Accordingly, images are obtained during the development of ischemia and at its peak rather than at the time when ischemia is resolving. However, the heart rate and workload achieved with TME is usually higher. Whether imaging during peak exercise with SBE offsets the potential benefit of a higher workload achieved with TME in the detection of ischemia has not been previously evaluated. This study was therefore undertaken prospectively to evaluate the comparative accuracy of SBE and post–
treadmill exercise echocardiography in detecting ischemia in the same patients with suspected or known CAD. In addition, the quality of the echocardiographic images acquired as well as the sonographers’ and patients’ preference was compared between the two modalities.

METHODS

Patient population. The study group consisted of consecutive patients with known or suspected CAD who underwent or were likely to undergo coronary angiography within 30 days of the exercise studies. The institutional review board of Baylor College of Medicine approved the study protocol. All patients gave informed consent before participation. Patients were excluded if they had a recent myocardial infarction (six weeks), were clinically unstable or had moderate or severe valvular lesions or unstable angina, or were in New York Heart Association class III or IV. Subjects with ventricular tachycardia, hypotension (systolic blood pressure <100 mm Hg) or hypertension (systolic blood pressure >180 mm Hg), and those unable to exercise were also excluded.

Supine bicycle and post–treadmill exercise echocardiography. All patients underwent both supine bicycle and treadmill exercise echocardiography. The two tests were performed at least 4 h apart, and both were symptom limited. The order of the stress modality was randomized. Echocardiography was performed using a Hewlett-Packard Sonos-2000 (Andover, Massachusetts) ultrasound system with 2.5-MHz transducer. For an individual patient, the same sonographer (out of four) performed both SBE and TME studies.

For the bicycle exercise, a variable load supine bicycle ergometer (American Echo, Inc., Kansas City, Missouri) was used with head tilt of 0 to 20° to obtain the best echo windows for imaging. After obtaining the rest images from the standard parasternal and apical views, patients pedaled at constant speed beginning at a workload of 25 to 50 W and increasing by 25 W every 3 min. Parasternal long- and short-axis, apical two- and four-chamber views were acquired in the supine position at each workload. Imaging from the apical window was facilitated with lateral tilting of the bicycle up to 25° during acquisition.

For the treadmill stress test, the standard Bruce protocol was used. Images were acquired at rest and immediately after treadmill exercise in a similar set of views to bicycle exercise as previously described (2). Acquisition of the first images was obtained within 9 to 25 s (mean 15 s), and all images within a mean of 58 s (range 39 to 85 s) of termination of exercise. For both stress modalities, images were digitized on-line using a TomTec digital system. The 12-lead electrocardiogram was continuously monitored and blood pressure determined at 3-min intervals during exercise, at peak stress and 3 min after stress. Criteria for interrupting either supine or treadmill exercise test were severe chest pain, diagnostic ST segment shift for ischemia ≥2 mm, extreme fatigue, excessive blood pressure rise (systolic blood pressure >240 mm Hg, diastolic blood pressure >120 mm Hg), limiting dyspnea or reaching maximal age-predicted heart rate. At the conclusion of both tests, the sonographers and the patients responded to a written questionnaire to determine their preference with regard to the exercise modalities.

Echocardiographic analysis. Digitized images at baseline and maximal exercise from each session (peak exercise for SBE and immediately after exercise for TME) were interpreted in a random order (type of stress and patient) by two experienced observers blinded to all other data. For bicycle exercise, only the peak exercise images were used during stress to allow masking the type of exercise modality during interpretation. Furthermore, all other identifiers on the quad-screen were deleted (i.e., name, heart rate and stage and time of exercise). Regional ventricular function was interpreted according to the recommendations of the American Society of Echocardiography using a 16-segment left ventricular model. Wall motion scoring was as follows: 1 = normal or hyperdynamic, 2 = hypokinesia, 3 = akinesia and 4 = dyskinesia. A normal response was defined as a normal or hyperdynamic function during exercise, ischemia as the development of new wall motion abnormality or worsening of resting hypokinesia, whereas a fixed abnormality was defined as a wall motion abnormality at rest without development of ischemia.

A wall motion score index (WMSI) was derived for the total left ventricle as the sum of regional scores divided by all segments visualized. The spacial extent of regional ischemia induced by either test was assessed as the total number of ischemic segments. The severity of regional ischemia was defined as the regional WMSI, derived as the wall motion score in segments rendered ischemic divided by the number of ischemic segments. The overall technical quality of the echocardiographic images during each stress session was assessed as excellent, good, fair or uninterpretable (6).

For the purpose of comparison with coronary angiography, the anterior septal segments, anterior segments and apex were matched to the territory of the left anterior descending artery, the posterolateral segments to the circumflex coronary artery, and the inferior septum and infero-posterior segments to the right coronary artery (2). Involvement of isolated posterior segments was assigned to the circumflex artery territory.
Quantitative coronary angiography. Coronary angiography was performed in multiple projections using the standard Judkins technique. Coronary angiograms were obtained within four weeks of study enrollment. There were no myocardial infarction or any revascularization procedures performed between the echocardiographic studies and coronary angiography. An independent experienced observer using the CASS system (Pie Medical Instruments, Maastricht, The Netherlands) quantitated the coronary angiograms. Significant coronary artery stenosis was defined as >50% narrowing of the reference lumen diameter.

Statistical analysis. Continuous data are presented as mean ± SD. Student paired t test or signed rank test was performed to determine differences between mean values for continuous variables where appropriate. Categorical variables were compared using a chi-square test. Analysis of variance was used to compare results in different groups. If the P value was significant, a Newman–Keuls multiple comparison test was performed. Kappa statistics were used to evaluate concordance in image interpretation. Sensitivity and specificity were determined using standard definitions. Significance was set at p ≤ 0.05.

RESULTS

A total of 75 patients were enrolled. One patient was excluded because of uninterpretable images during both SBE and TME. The remaining 74 patients were therefore analyzed. The mean age was 59 ± 8.6 (31 to 76) years. Table 1 provides a summary of the clinical data of the study population. Thirty-six patients were on nitrates (49%), 28 (38%) on beta-adrenergic blocking agents and 26 (35%) on calcium-channel blocking agents. Medications were discontinued on the day of stress testing in 50% of patients. Sixty-seven patients (90%) underwent coronary angiography. There were 57 patients with CAD: 15 with single-vessel disease, 24 with two-vessel disease and 18 with three-vessel disease. The remaining 10 patients had no significant atherosclerotic lesions. Forty patients had significant left anterior descending artery stenosis, 40 had circumflex disease and 36 had right coronary artery stenosis.

Hemodynamic changes during SBE and TME. Table 2 summarizes the hemodynamic changes with each stress modality. Thirty-eight patients underwent TME first and 36 underwent SBE first. The two tests were separated by at least 4 h (range 4 to 6 h). Exercise duration averaged 6.6 ± 2.3 min (range 3 to 13) on the TME and 11.8 ± 2.8 min (range 6 to 21) on the SBE (p < 0.001). Maximum workload achieved on the supine bicycle ergometer was 111 ± 32 W (range 50 to 200). Metabolic equivalents achieved during TME were higher than during SBE (Table 2). The maximum heart rate was higher during TME (Table 2), where patients reached 85 ± 12% (54 to 113) of maximum age-predicted heart rate compared with 74 ± 12% (44 to 112) of the target heart rate during SBE. However, the systolic blood pressure was higher at maximal exercise during SBE. The double product at peak exercise was therefore similar with both stress tests (p = 0.28) (Table 2).

Detection of ischemia with SBE and TME. During TME, there were 28 normal stress echocardiographic studies, 38 demonstrating ischemia and 8 showing fixed wall motion abnormality. On the other hand, during SBE, there were 22 normal studies, 47 ischemic and 5 showing fixed wall motion abnormalities (Table 3). Concordance in exact overall interpretation of the studies as normal, ischemic or fixed abnormality was high at 80% (kappa value = 0.63). More studies, however, showed ischemia by SBE compared with TME (Table 3, p < 0.001).

During TME and SBE, WMSI increased significantly with exercise compared with baseline (Fig. 1). Wall motion score index was higher during SBE compared with TME.
The extent of ischemia induced with SBE was larger than that by TME as manifested by the larger number of ischemic segments during exercise (Fig. 2). The extent of ischemia was larger regardless of whether the analysis was performed considering all segments rendered ischemic during exercise or those segments which have a normal baseline wall motion (Fig. 2). The severity of ischemia in the abnormal segments assessed as regional WMSI, however, was similar (exercise WMSI in abnormal segments of 2.05 ± 0.86 for TME and 2.06 ± 0.76 for SBE, p = 0.88).

In comparison with quantitative angiography, overall sensitivity for detection of coronary disease using any wall motion abnormality during exercise was 82% for SBE and 75% for TME (Fig. 3) and for detection of ischemia was 75% and 61%, respectively (p = 0.45 and 0.15). The sensitivity for single-vessel and multivessel disease is shown on Figure 3. These differences did not reach statistical significance. In the 10 patients with normal coronary arteries, stress echocardiographic studies were normal in nine patients during TME and in eight during SBE.

Quality of the stress studies, sonographers’ and patients’ preference. Lateral angulation on SBE to enhance imaging from the apical window during exercise averaged 14 ± 3° (range 5 to 22). The distribution of image quality was similar with the two tests (p = 0.21; Fig. 4). Preference of patients and sonographers for the type of stress imaging modality is shown in Figure 5. Overall, patients and sonographers preferred SBE.

DISCUSSION

The current investigation confirms that supine bicycle exercise echocardiography is a viable alternative to the posttreadmill approach. Even though a higher workload and peak heart rate were achieved with TME, a higher maximal exercise blood pressure was attained with SBE, resulting in a similar double product with both modalities. The frequency and extent of ischemia achieved, however, was higher with bicycle exercise, a reflection of imaging during stress rather than after maximal stress. Image quality was similar using the two modalities, and the majority of

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**Figure 1.** Wall motion score index (WMSI) at rest and maximal exercise in the 74 patients undergoing supine bicycle exercise and post–treadmill exercise echocardiography. Black bars = rest; hatched bars = peak exercise.

**Figure 2.** Extent of ischemia achieved during supine bicycle exercise (SBE) and post–treadmill exercise (TME) echocardiography, shown as number of ischemic segments. NL = normal; WM = wall motion. Black bars = TME; hatched bars = SBE.

**Figure 3.** Overall sensitivity and specificity for supine bicycle exercise and post–treadmill exercise echocardiography, in the detection of coronary artery disease. Black bars = supine bicycle; hatched bars = treadmill.

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**Table 3.** Concordance Between Results of Supine Bicycle and Post–Treadmill Exercise Echocardiography

<table>
<thead>
<tr>
<th>Supine Bicycle Echo</th>
<th>Treadmill Exercise Echo</th>
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<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Ischemia</td>
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<tr>
<td>Normal</td>
<td>20</td>
<td>2</td>
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<tr>
<td>Ischemia</td>
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<td>35</td>
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<tr>
<td>Fixed WMA</td>
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<td>1</td>
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<tr>
<td>Total</td>
<td>28</td>
<td>38</td>
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Echo = echocardiography; WMA = wall motion abnormality.
patients and sonographers preferred SBE to TME in this investigation.

**Supine bicycle exercise vs. post–treadmill exercise echocardiography.** Previous echocardiographic studies have shown that, with bicycle exercise as the stress modality, detection of ischemia is higher when imaging at peak exercise rather than immediately after exercise. In a study by Hecht et al. (5), imaging at peak exercise was more sensitive than after supine bicycle exercise (94% vs. 83%) and identified patients with multivessel disease more accurately. Likewise using upright bicycle, Ryan et al. (7) noted a higher sensitivity of peak exercise compared with postexercise imaging (91% vs. 83%). Currently, the posttreadmill approach for exercise echocardiography is widely used for the evaluation of CAD. To detect ischemia, TME relies on the persistence of exercise-induced ischemia for a short duration after maximal exercise. Whether imaging during peak exercise with SBE offsets the potential benefit of the higher workload usually achieved with TME in the detection of ischemia has not been previously evaluated.

The present investigation is the first to compare the results and relative merits of the two stress modalities in the same patients. The findings of overall similar accuracy and higher detection of ischemia with SBE compared with TME can be explained by the hemodynamic changes induced by each stress modality and the timing of image acquisition. Although treadmill exercise results in a higher heart rate and workload, a number of hemodynamic changes occur with supine exercise that induce and potentially accentuate myocardial ischemia. Higher systolic and diastolic blood pressures are observed in the supine position, as demonstrated in this and previous reports, resulting in a similar double product (8,9). Furthermore, an increase in end-systolic and end-diastolic ventricular volumes occurs in the supine position, as shown earlier with radionuclide angiography at rest and during exercise (10,11). Therefore, myocardial wall tension (directly related to volume and pressure) rises precipitously with supine exercise, increasing myocardial oxygen demand. Furthermore, the increase in left ventricular filling pressures with supine exercise (9,12) may decrease the coronary perfusion pressure gradient during diastole (13). The potentiating effect of supine exercise on ischemia, as well as imaging during peak exercise, probably resulted in the detection of a more extensive regional dysynergy during SBE in our series.

The quality of images was comparable between the two modalities. The availability of bicycles tailored for echocardiography may have facilitated image acquisition and improved the quality of images by allowing lateral tilting of the apparatus and having a drop section to facilitate imaging from the cardiac apex. The importance of a drop section for the apical views had been well recognized and available for rest and TME imaging. Although the exercise duration of SBE was longer than TME, patient preference favored SBE predominantly because of ease, more control of the exercise and less strain on the knee joints. Of the four sonographers involved in the study, overall preference favored SBE mostly because of fewer time constraints to obtain the stress images, although all sonographers were exclusively trained with TME for several years before the study.

**Advantages and limitations.** The patient population represents a relatively select group of patients in whom the majority underwent quantitative coronary angiography to serve as standard for comparison. However, within this selection, patients were enrolled consecutively, without screening for echocardiographic image quality or a priori preference of one or the other stress modality. Few patients had resting wall motion abnormalities, which may influence overall interpretation. However, we wanted to test the comparability of the two techniques in a population referred for exercise echocardiography, which frequently includes patients with previous myocardial infarction. Analysis of total ischemic segments as well as those with normal baseline wall motion yielded similar results. There were only

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*Figure 4. Distribution of echocardiographic image quality with supine bicycle exercise and post–treadmill exercise echocardiography. Black bars = supine bicycle; hatched bars = treadmill.*

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*Figure 5. Distribution of patient and sonographer preference for the stress echocardiography modality. Black bars = supine bicycle; hatched bars = treadmill; open bars = equal.*
a few patients with normal coronary arteries to allow an accurate comparison of specificity. Traditionally, specificity with either modality has been high. However, further studies are needed to assess the comparative normalcy rate or specificity with the two techniques.

To maintain the masking in interpretation of the studies, only images at rest and maximal exercise were displayed. In our experience, display of various stages of exercise in the quad-screen during SBE (rest, stage 1, 2 and peak exercise) facilitates interpretation of stress echocardiographic studies and may allow detection of more subtle ischemic changes by evaluating the progression of ventricular function with exercise, similar to graded pharmacologic stress.

Conclusions. Patients achieve a similar rate–pressure product during SBE and TME. However, ischemic wall motion abnormalities at the time of imaging are more frequent and more extensive during supine bicycle echocardiography, which may increase the detection of CAD and facilitate interpretation of ischemia. These findings along with patient and sonographer preference make SBE a valuable stress echocardiography modality in the evaluation of patients with CAD.

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REFERENCES