Clinical Application of Exercise Stress Echocardiography: Supine Bicycle or Treadmill?

Alessandra Dagianti, MD, Maria Penco, MD, Alberto Bandiera, MD, Luca Sgorbini, MD, and Francesco Fedele, MD

Although exercise stress echocardiography is currently used to evaluate coronary artery disease (CAD) patients, the best exercise methodology is still undefined. The objectives of the study were: (1) to compare supine bicycle stress echocardiography (SBSE) and treadmill in the evaluation of CAD; and (2) to define, in normal subjects, the different behavior of factors determining MVO_2 with treadmill and SBSE. We selected 10 male patients with CAD (group A), and 10 male control subjects (group B). Each patient underwent SBSE and treadmill testing in random order. We studied heart rate, systolic blood pressure, heart rate × systolic blood pressure, and end-diastolic and end-systolic volume indexes. In group A, we also studied wall motion score index (according to the American Society of Echocardiography) and in group B, systolic blood pressure/end-systolic volume index. The results were as follows: *Group A*: SBSE resulted in significantly lower work load, heart rate, and significantly higher systolic blood pressure, heart rate × systolic blood pressure, end-diastolic volume index, end-systolic volume index, and wall motion score index. SBSE showed wall motion abnormalities in each patient, whereas treadmill did not detect wall motion abnormalities in 4 patients (3 single-vessel; 1 multivessel); of the other 6 patients, 2 showed a lower wall motion score index and 4 did not show any difference in left ventricle kinetics with the 2 methodologies of exercise. Mean acquisition time for postexercise images was 72 ± 6 seconds. *Group B*: SBSE resulted in lower work load, heart rate, heart rate × systolic blood pressure, systolic blood pressure/end-systolic volume index, and higher end-diastolic volume index and end-systolic volume index. Systolic blood pressure was similar with SBSE and treadmill testing. In conclusion, our experience suggests SBSE is a highly accurate diagnostic tool for evaluating CAD compared with treadmill testing; the maximum cardiovascular performance can be achieved with lower values of heart rate, suggesting the echo test is more feasible. Treadmill testing could lose important information about the existence, extension, and location of CAD; in contrast, SBSE detects even small, quickly reversible wall motion abnormalities.

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Exercise stress echocardiography is currently used to evaluate risk for inducible ischemia. This method has achieved more widespread acceptance only in the past few years with the advent of digital acquisition and classic loop for quadrant display, facilitating comparison of rest and postexercise images.[1]

Stress echocardiography may involve either treadmill or supine–upright bicycle. These methodologies allow the acquisition of echo images during different periods and, in addition, a different body position could determine important effects on cardiovascular function. With treadmill exercise, more muscle groups are recruited, many adults are more familiar with this type of exercise, and it is also less dependent on subject's cooperation to maintain a constant workload during a specific protocol. Therefore, higher workload and greater maximal heart rate are typically achieved with treadmill exercise.[2,3]

A delay of postexercise echocardiographic image acquisition allows a better visualization of regional wall motion; however, the delay of ≥1 minute between the end of exercise and echocardiographic image acquisition may leave quickly reversible wall motion abnormalities undetected.[4–8] On the other hand, supine bicycle exercise permits imaging to be performed during and at peak exercise rather than only during the recovery period. Since wall motion abnormalities may sometimes recover rapidly, peak exercise imaging may increase sensitivity for the detection of coronary artery disease (CAD).[9–13] Furthermore, compared with treadmill and upright bicycle exercise, supine bicycle exercise increases venous return as well as central blood and left ventricular volumes, consequently lowering ischemic heart rate threshold.[9–14] A review of the literature shows that very few data are available comparing supine bicycle and treadmill modalities in the same group of subjects.[9,15,17] Accordingly, this study aimed to define: (1) supine bicycle stress echocardiography (SBSE) diagnostic accuracy in detecting myocardial ischemia with all images acquired during exercise, compared with treadmill exercise echocardiography, and with all images acquired after exercise, in a population of CAD patients; and (2) the different behavior of factors determining MVO_2 with treadmill and supine bicycle exercise, in a population of healthy subjects.

From the Division of I and III Cardiology, Department of Cardiovascular and Respiratory Sciences, La Sapienza University, Rome, Italy; and Department of Cardiology, University of L'Aquila, L'Aquila, Italy.

Address for reprints: Alessandra Dagianti, MD, Department of Cardiovascular and Respiratory Sciences, La Sapienza University, Viale del Policlinico 155, 00161 Rome, Italy.

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METHODS

The study group consisted of 20 subjects; 10 male patients (group A) were selected from a group of 150 subjects referred to the stress echo laboratory of our institute for evaluation of possible CAD precordial pain. Selection criteria were as follows: (1) recurrent chest pain; (2) absence of previous myocardial infarction; (3) absence of wall motion abnormalities as determined by two-dimensional (2D) rest echocardiogram; (4) positive exercise electrocardiograms (12 standard leads) defined as development of >0.01 mV horizontal or downsloping ST-segment depression at 0.08 seconds after the J point in a lead with a normal baseline ST-segment development of severe ventricular arrhythmia; and (5) presence of significant CAD as defined by a >70% reduction of lumen area in any of the 3 coronary arteries or their primary branches, or >50% lumen narrowing of the left main coronary artery.

A control group, consisting of 10 male subjects (group B), were matched for age; they were considered healthy on the basis of symptoms, risk factors, and exercise electrocardiography and did not undergo cardiac catheterization.

Each subject underwent, in random order, SBSE and treadmill exercise, performing the 2 tests on different days within a 5-day period, at the same hour and under the same environmental conditions. In group A, all exercise tests were obtained within 2 weeks of cardiac catheterization. In patients receiving treatment, β-adrenergic blocking agents were discontinued for >48 hours and long-acting nitrates and calcium antagonists for >24 hours before the test. The study protocol was approved by La Sapienza University Ethical Committee on Human Research and informed written consent was obtained from all subjects.

Stress echocardiography: SBSE was performed with supine bicycle ergometry on a tilting exercise table, with the table tilted to 30° of the left lateral decubitus position. Exercise started with a workload of 25 W that increased by 25 W every 2 minutes. When testing was not symptom-limited, the value of 85% of maximum age-predicted heart rate was always reached. Echocardiographic and electrocardiographic monitoring and symptom notation were performed throughout testing, with blood pressure determined every 2 minutes. Endpoints for test termination were as follows: (1) echocardiographic detection of wall motion abnormalities not present at baseline; (2) symptoms judged to be unacceptable by the supervising cardiologist (angina, severe fatigue, or dyspnea); (3) myocardial ischemia or serious arrhythmia at electrocardiography; (4) systolic blood pressure >220 mm Hg or diastolic blood pressure >120 mm Hg; and (5) exercise-induced muscular fatigue.

A 2D echocardiographic examination was performed with the use of a commercially available wide-angle, phased array imaging system (Vingmed Sonotron CFM800) with a 3.25 mHz transducer, immediately before and throughout the entire test and recovery period, with standard parasternal long–short axis views and apical 2-, 3-, and 4-chamber views acquired in the supine position. A Vingmed cineview was used for 4-quadrant display of digitized images for simultaneous comparison of rest, peak-exercise, and postexercise studies. Eight frames per cardiac cycle, triggered from the R wave at intervals of 67, 50, or 33 msec depending on heart rate, were displayed. Continuous 3-lead electrocardiographic monitoring was used with a 12-lead electrocardiogram during each stage with precordial electrodes moved to avoid encroachment on the transducer.

The entire study was continuously recorded on super VHS tape. Endocardial visualization was required for analysis to proceed. According to our previous experience, wall motion was quantitatively assessed by the evaluation of systolic thickening as normal (>5 mm excursion), hypokinetic (2–5 mm excursion), akinetic (absent thickening), or dyskinetic (systolic wall thinning and outward motion).[18] Furthermore, each segment was qualitatively scored by 2 independent observers without knowledge of clinical and angiographic data, with differences in opinion resolved by consensus, as follows: 1 = normal, 2 = hypokinesia, 3 = akinesia, 4 = dyskinesia. An abnormal study was defined by onset of segmental wall motion abnormalities during or after exercise. To further evaluate the resolution of ischemia from peak exercise to the recovery period, the 5 views were consolidated into the standard 16 segments adopted by the American Society of Echocardiography to avoid duplication of the same areas on multiple views.[19] Echocardiographic recordings were previously coded and interpreted at random in our laboratory by 2 of the investigators, who were blinded to clinical data, with interobserver agreement on 92% of the examined segments. One observer reviewed a random sample of 80 studies twice, with intraobserver agreement on 98% of the examined segments.[18]

All patients underwent standard Bruce protocol treadmill exercise testing to a symptom-limited maximal exercise with continual 3-lead monitoring and 12-lead electrocardiography performed during each stage of exercise. Clinical and blood pressure responses were monitored and assessed during each stage of exercise. Echocardiographic monitoring was performed before and after exercise in the supine position; mean acquisition time for postexercise images was 72 ± 6 seconds.

Endpoints for test termination were the same as those adopted for SBSE with the exclusion of echocardiographic detection of wall motion abnormalities at peak exercise.

Study parameters: At baseline and at peak exercise, the following parameters were evaluated: heart rate, systolic blood pressure, rate–pressure product, left ventricle end-systolic volume index, and left ventricle end-diastolic volume index[19]; in group A only, we also evaluated wall motion score index. In group B, we also studied the "systolic blood pressure/left ventricle end-systolic volume index" ratio (systolic blood pressure/end-systolic volume index) as a noninvasive index of the left ventricle contractile state.[20] We stud-

TABLE I Characteristics of Patient Population

	Group A	Group B
Age (yrs)	54 ± 7	51 ± 8
Chest pain history	10	0
Diabetes	4	0
Antianginal drugs	10	0
Calcium antagonists	6	0
Nitrates	10	0
Coronary arteriography		
Single vessel	4	—
Double vessel	4	—
Triple vessel	2	—

TABLE III Group A: Wall-Motion Score Index (WMSi)

Patient Number	SBSE	Treadmill	CAD (Vessel)
1	1.25	1	1
2	1.12	1	1
3	1.12	1	1
4	1.25	1	2
5	1.43	1.25	1.
6	1.37	1.18	2
7	1.50	1.50	2
8	1.56	1.56	3
9	1.50	1.50	2
10	1.43	1.43	3

CAD = coronary artery disease; SBSE = supine bicycle stress echocardiography.

TABLE II Group A: Exercise Test Results

	SBSE	Treadmill
Work load (kg/min)	488 ± 187*	973 ± 8
HR (beats/min)	134 ± 19†	162 ± 19
SBP (mm Hg)	191 ± 22‡	180 ± 17
Rate–pressure product $\times 10^3$	26 ± 6*	29 ± 6
EDV_i (cm^3)	102 ± 31*	99 ± 29
ESV_i (cm^3)	55 ± 12‡	49 ± 12
WMS_i	1.4 ± 0.2‡	1.2 ± 0.2

* p <0.005.
† p <0.001.
‡ p <0.05.
EDV_i = end-diastolic volume corrected for body surface area; ESV_i = end-systolic volume corrected for body surface area; HR = heart rate; SBP = systolic blood pressure; SBSE = supine bicycle stress echocardiography; WMS_i = wall-motion score index.

TABLE IV Group B: Exercise Test Results

	SBSE	Treadmill
Work load (kg/min)	854 ± 106†	1,694 ± 293
HR (beats/min)	142 ± 14†	166 ± 20
SBP (mm Hg)	200 ± 25	193 ± 13
Rate–pressure product $\times 10^3$	28 ± 5*	32 ± 4
EDV_i (cm^3)	107 ± 24*	95 ± 18
ESV_i (cm^3)	39 ± 12‡	33 ± 13
SBP/ESV_i	5.5 ± 1.5§	6.3 ± 2.2

* p <0.005.
† p <0.001.
‡ p <0.05.
§ p <0.0005.
SBP/ESV_i = Systolic blood pressure/end-systolic volume corrected for body surface area. Other abbreviations as in Table II.

ied this parameter only in group B because the systolic blood pressure/end-systolic volume index ratio is not a reliable contractility index of an ischemic left ventricle.[19] In both groups of patients, we also evaluated heart rate and rate–pressure product at 75% predicted maximal heart rate (predicted maximal heart rate; 220 − age).

Cardiac catheterization: All group A patients underwent left-sided cardiac catheterization and coronary angiography before SBSE and treadmill tests. For quantitative analysis of coronary artery stenoses, a previously described and validated method was used.[21] Significant coronary artery stenosis was defined as mentioned above. Angiograms were reviewed by 2 angiographers who were unaware of the results of stress echocardiography.

Statistical analysis: The Student's 2-tailed *t* test for paired data for comparison between SBSE and treadmill tests was performed. Data are presented as mean ± SD. A p value <0.05 was considered statistically significant.

RESULTS

The clinical characteristics of the study population are presented in Table I.

Peak exercise: Group A: At peak exercise (Table II), the mean workload with supine bicycle exercise was significantly lower compared with treadmill; SBSE showed significant lower values of heart rate, higher values of systolic blood pressure, and lower values of rate–pressure product compared with treadmill. SBSE resulted in significantly higher values of end-diastolic volume index and end-systolic volume index than treadmill exercise. The ability of SBSE to detect CAD was demonstrated by the values of wall motion score index (Table III), which were significantly higher than treadmill: in fact, each patient of this group showed left ventricle wall motion abnormalities at peak exercise whereas, at the moment of after-treadmill image acquisition, 4 patients did not show any wall motion abnormalities (3 single-vessel and 1 double-vessel disease); of the other 6 patients with wall motion abnormalities at SBSE, 2 showed a lower echo score index (1 single-vessel and 1 double-vessel) with treadmill and only 4 patients did not show any difference in left ventricle kinetics with the 2 methodologies of exercise.

Group B: The stress test was interrupted for fatigue in all subjects. SBSE (Table IV) resulted in significantly lower values of workload, heart rate, and rate–pressure product, and higher values of end-diastolic volume index and of end-systolic volume index. Systolic blood pressure values were similar with SBSE and treadmill. Systolic blood pressure/end-systolic volume index ratio was significantly lower at peak supine exercise compared with treadmill exercise.

TABLE V Submaximal Exercise (75% PMHR) Test Results

	Group A		Group B	
	SBSE	Treadmill	SBSE	Treadmill
SBP (mm Hg)	174 ± 14.9*	153.5 ± 13.6	183 ± 17*	157 ± 14
HR × SBP × 10^3	21 ± 2.5†	19 ± 2.6	25 ± 3.3†	21 ± 2.6

* p <0.005.
† p <0.05.
PMHR = predicted maximal heart rate; other abbreviations as in Table II.

Submaximal exercise (75% predicted maximal heart rate): Group A (Table V): The mean heart rate at 75% predicted maximal heart rate was 121 ± 12 beats/min. SBSE resulted in significantly higher systolic blood pressure and rate–pressure product than treadmill exercise.

Group B (Table V): The mean heart rate at 75% predicted maximal heart rate was 133 ± 12 beats/min. SBSE resulted in significantly higher systolic blood pressure and rate–pressure product than treadmill exercise.

DISCUSSION

Stress echocardiography has received special attention because of the possibilities it offers for the study of abnormal wall motion after stress-induced ischemia.

The first studies date from 1978–1979 and used M-mode echocardiography.[22,23] They showed that the method was of undoubted diagnostic value but also emphasized its limits, especially the lack of spatial orientation, which made it possible to explore only limited areas of the myocardial wall. The 2D echocardiography studies seemed to be of wider value.[23] Nevertheless, the technical difficulties of carrying out an echocardiographic examination during exercise have also been pointed out; in fact, the low feasibility of peak-exercise image acquisition broadened the diffusion of posttreadmill and pharmacologic echocardiographic protocols. However, the introduction of digital imaging techniques (digital acquisition and classic loop for quadrant display) has lead to significant improvement in the feasibility of exercise echocardiography over the past few years, facilitating comparison of peak and postexercise images. In fact, in a recent study conducted by Quinones et al[24] on approximately 300 patients, a 99% feasibility rate for exercise echo was reported. These investigators believed that feasibility has ceased to be an issue altogether; in our experience, the rate of unfeasible examinations for exercise echo has dropped from an initial 30% to a mere 5% today.[1]

The exercise methodology of choice for stress echocardiography is still undefined, and treadmill and SBSE have their advocates. After treadmill exercise testing, the echocardiographic examination is carried out on the supine position 30–60 seconds after the end of exercise.[4–8] In support of the validity of this method, some investigators[2,3] state that (1) treadmill exercise testing provides more vigorous exercise even when the patient's cooperation is less than perfect; and (2) the echocardiographic examination carried out at the end of exercise makes it possible to visualize wall motion abnormalities while eliminating all the technical difficulties associated with obtaining an echocardiogram during exercise. Additionally, in our experience, wall motion abnormalities are better visualized at the end of exercise during the recovery phase.[4] However, we always considered it useful to carry out echocardiographic examination during both exercise and the entire recovery period, so that any wall motion abnormalities could be identified early and its evolution could be studied. Our studies showed that wall motion abnormalities disappeared in 26% of cases within 1 minute after the end of exercise, consequently preventing the recording of wall motion abnormalities with an echocardiographic examination carried out shortly after exercise.[4] In addition, this methodology of exercise accentuated the differences between well-perfused and poorly perfused myocardial segments, increasing the possibility of detecting wall motion abnormalities. Indeed, during sympathetic stimulation, the well-perfused segments tended toward hyperkinesia, whereas the poorly perfused segments could present decreased motility. In our experience, as well as in that of other investigators[25,26] who have used the supine position during exercise with the bicycle ergometer, the highest percentage results and the best quality images were obtained by placing the patient in the supine position, with the legs raised from the bed and the trunk raised to form an angle of 30° and rotated slightly to the left. A stress echocardiogram is obtained more easily in this position; in addition, a higher venous return flow results in augmented heart volumes. Left ventricular wall stress is thus increased, which means that the threshold for ischemia will be reached at lower arterial pressure and heart rate product values. This was confirmed by our previous findings[27] showing that patients performing a stress test in the supine position reached a lower angor threshold compared with that obtained with a stress test performed in the upright position.

PREVIOUS STUDIES

More direct comparison between bicycle and treadmill exercise during the degree of submaximal exercise in the same group of patients has been made in a previous study where echo stress was not utilized.[15]

These data showed that at comparable submaximal heart rates, treadmill exercise in normal subjects resulted in significantly lower cardiovascular stress than SBSE.

Similarly, the results of Nieberber et al[28] showed that at equivalent submaximal exercise levels, CAD patients had higher degrees of cardiovascular stress during upright bicycle exercise than during treadmill exercise. A more recent CAD-patient study[16] compared hemodynamic and electrocardiographic response to submaximal treadmill and supine bicycle exercise; these data also showed that submaximal supine bicycle exercise resulted in significantly higher values of systolic blood pressure and rate–pressure product than treadmill exercise. In addition, supine bicycle electrocardiographic exercise was determined to be significantly more sensitive for detecting CAD than treadmill electrocardiographic exercise.[16] Our findings on hemodynamic data at comparable submaximal heart rates (75%) are consistent with these results. Few studies focused on the comparison between supine bicycle and treadmill tests by detection of wall motion abnormalities, a highly specific indicator of CAD. Hetch et al[9] compared, in the same patient undergoing coronary arteriography, SBSE and thallium-201 single-photon emission computerized tomographic (SPECT) exercise treadmill testing. Their physiologic data are consistent with our results even if they showed no statistical difference of rate–pressure product between the 2 methodologies of exercise. The evaluation of CAD by SBSE and thallium-201 SPECT showed that there were no differences in sensitivity (90% vs 92%), but a higher specificity (80% vs 65%), and predictive accuracy of SBSE (87% vs 85%). Furthermore, SBSE was more sensitive for evaluation of the left anterior descending CAD (97% vs 82%, $p < 0.005$) and more specific in evaluating the right CAD (88% vs 66%, $p < 0.01$) and for evaluation of the vessels involved in the triple-vessel disease (93% vs 69%, $p < 0-01$).

Furthermore, few data compared the ability of peak and postexercise imaging in evaluating CAD. Sawada et al[29,30] and Dohan et al[31] have used peak exercise digital acquisition imaging during upright bicycle exercise, and Presti et al[32] compared the sensitivities of peak and postexercise imaging in 21 patients. They used upright bicycle acquisition of apical 2- and 4-chamber views followed by supine acquisition of apical and short-axis views within 3 minutes after the end of exercise. The sensitivity of peak and postexercise imaging was 100% versus 70% respectively. Hecht et al[10] showed that SBSE results for identification of CAD patients are comparable or superior to those in post treadmill or pharmacologic reports. They also showed, in the same group of patients, the superiority of peak exercise imaging compared with postexercise imaging because of a normalization of 40% of the segments from peak to postexercise imaging.[11] Furthermore, the postexercise SBSE sensitivity and specificity were similar to those reported in other studies.[11]

However, despite the generally superior sensitivity of SBSE compared with postexercise imaging, the results of previous studies did not prove the superiority of the SBSE technique, because the same group of patients did not undergo both procedures (treadmill and SBSE).

One of the original aspects of this study was the direct comparison in the same subject of these 2 different echocardiographic modalities. Our data showed that SBSE resulted in significantly higher cardiovascular stress than treadmill exercise with higher left ventricle end-diastolic and left ventricle end-systolic volumes in both groups of patients. Consequently, SBSE allowed a better detection of wall motion abnormalities in CAD patients. Furthermore, the extent of myocardial ischemia (number of wall motion abnormality segments) was higher during SBSE compared with treadmill exercise; these differences could depend on body position, which could result in different effects on cardiovascular function as mentioned above. Our data are consistent with those previously reported by Badruddin et al,[17] and provide objective validation of the expectation that imaging during peak ischemia would yield better results than imaging while ischemia is progressively resolving after exercise.

CONCLUSIONS

In conclusion, our experience suggests SBSE is a highly accurate diagnostic tool compared with treadmill exercise. In comparison with treadmill testing, SBSE can reach the maximum cardiovascular performance with lower values of heart rate, suggesting the echo test is more feasible. In addition, treadmill testing could lose important information about the existence, extension, and location of CAD; on the contrary, SBSE detects even small, quickly reversible wall motion abnormalities.

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