Exercise Echocardiography After Coronary Artery Bypass Surgery: Correlation With Coronary Angiography

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Objectives. Our aim was to assess, in patients after coronary artery bypass surgery, how well exercise echocardiography predicts the presence of vascular compromise on angiography.

Background. Because late graft failure frequently occurs after bypass surgery, a reliable noninvasive technique is needed to identify those patients who would benefit from angiographic study.

Methods. In 182 patients, a total of 213 symptom-limited treadmill exercise electrocardiograms (ECGs) and exercise echocardiograms were performed in association with coronary and bypass angiography 2 weeks to 21 years after bypass surgery.

Results. There were more inconclusive exercise ECGs (28%) than exercise echocardiograms (9%). The positive predictive value was 85% for the exercise echocardiogram versus 62% for the exercise ECG; the corresponding negative predictive values were 81% versus 52%. The accuracy of the exercise echocardiogram was linked to the degree of underlying vascular compromise. After excluding cases with nondiagnostic results, due to either submaximal stress or poor image quality, the exercise echocardiogram detected 46 of the 60 cases with vascular compromise in one region (sensitivity 77%) and 47 of the 49 cases with compromise in two or three regions (sensitivity 96%). Similarly, an abnormal exercise echocardiogram had a positive predictive value of 71% for vascular compromise in one region and 98% for compromise in two or three regions. Most false negative exercise echocardiographic results were associated with posterolateral single-region vascular compromise on angiography.

Conclusions. This study confirms a high positive and negative predictive value of exercise echocardiography in the detection of vascular compromise in patients after bypass surgery. It is clearly superior to exercise electrocardiography in predicting which patients will have angiographically significant graft or arterial lesions, and it can be used to obtain a better selection of patients for angiographic study.

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Although coronary artery bypass surgery offers relief of symptoms and prolongation of life for selected patients, it has been plagued with a high long-term rate of graft failure. In our long-term studies, the 5-year failure rate has been 26% and the 10-year occlusion rate 41%, with evidence of atherosclerosis in 75% of the patent grafts (1,2).

Therefore, recurrence of myocardial ischemia can be expected in patients after bypass surgery for reasons that include graft failure, the progression of disease distal to the site of graft insertion or the development of significant stenoses in vessels that had little disease at the time of the original operation. We know that exercise electrocardiography has limitations in the detection of myocardial ischemia, especially in patients with abnormal results on the rest electrocardiogram (ECG) (3,4). In contrast, exercise echocardiography has emerged as a reliable and reproducible tool for detecting cardiac ischemia, its results correlating well with those of angiography and single-photon emission computed tomographic (SPECT) thallium studies (5–10). However, exercise echocardiography poses special challenges in patients after bypass surgery because many of these patients already have wall motion abnormalities that may make interpretation of the ultrasound data difficult. Two previous studies (11,12) have demonstrated accuracy of the exercise echocardiogram in the detection of compromised myocardium in these patients. However, both studies had a limited number of patients with complete revascularization. Only 6 of the 41 patients of Sawada et al. (11) and only 13 of the 125 cases of Crouse et al. (12) were without vascular compromise.

The purpose of this study was to assess the clinical utility of exercise echocardiography for the detection of the presence and extent of vascular compromise in a cross section of patients after coronary bypass surgery.

Methods

Study patients. As part of our long-term follow-up program, we routinely undertake exercise testing and angiography in all patients early and at 1, 5 and 10 years after bypass surgery regardless of symptoms (1,2). The study group consisted of these patients plus patients presenting with symptoms or with

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ECG changes during the study period (October 1991 to August 1993). There were 182 patients aged 33 to 73 years (mean 56). The interval between the study and their bypass operation ranged from 2 weeks to 21 years (mean 3.6 years).

Because the investigation was conducted for >1 year, some patients had more than one set of angiographic and exercise studies. In total, 213 angiograms with associated exercise ECG and exercise echocardiographic studies were performed in 182 patients. Of the 213 angiographic and exercise studies, 52 were performed in patients with symptoms, 13 in patients with recent ECG changes and 148 as part of the postbypass follow-up program in patients who had no symptoms by history and no recent ECG changes. Informed consent was obtained from all patients for all studies performed. This study was reviewed and approved by the Ethics and Research Committee of the National Defence Medical Centre (NDMC).

Exercise testing. All patients underwent symptom-limited maximal treadmill exercise using either the standard Bruce or the military NDMC protocol. The target heart rate was 85% of predicted maximum for age, and cardiac medications were withheld. The exercise ECG and exercise echocardiogram were performed during the same exercise test. Not all postbypass patients who had angiography during this time were included in this study. We did not attempt to perform exercise echocardiography in patients who would not otherwise have undergone exercise testing. No patient who was unable to exercise, had unstable angina or had had recurrence of discomfort identical to that of preoperative angina underwent exercise before angiography.

The exercise ECG was scored as abnormal if there was ≥1-mm horizontal or downsloping ST segment depression. It was considered inconclusive if the patient 1) had no significant ST segment changes but had not reached the target heart rate; 2) had ST-T changes during or after exercise that were not classically positive for ischemia; or 3) had ST segment anomalies at rest due to conduction defects or the use of digoxin.

Exercise echocardiography was performed before and just after peak exercise as described previously (7–10,12); a Hewlett-Packard Sonos 1000 echocardiograph and Microsonics DataVue/PreVue were used. The results were reviewed by an experienced echocardiographer without knowledge of the angiographic findings. Segmental regional wall motion analysis was performed with use of a 16-segment model. A normal response to exercise was defined by increased wall motion and an abnormal response by worsening or unimproved motion after adequate exercise and heart rate response. Akinetic segments or dyskinetic segments at rest were considered to indicate infarction and were excluded from analysis.

Coronary angiography. The interval between the exercise test and the coronary angiogram was ≤1 week in 201 of the 213 cases, between 1 and 2 weeks in 5 cases, between 2 weeks and 1 month in 4 cases and between 1 month and 6 weeks in 3 cases. The angiograms were interpreted by a panel of two angiographers who visually estimated the stenoses. As in other studies (7–12), significant compromise of vascular supply to a region was deemed present if the graft or the coronary artery was narrowed by ≥50% of the diameter of the artery.

Table 1. Results of Exercise Electrocardiography

Exercise Electrocardiograms	No.
Positive	93
Negative	60
Inconclusive	60
ST segment anomalies due to digoxin	13
Nondiagnostic ST segment changes	21
Failed target heart rate	16
Left bundle branch block	7
Right bundle branch block	1
Wolff-Parkinson-White syndrome	1
Nonspecific rest ST segment anomalies	1

Correlation with coronary angiography. We assessed the ability of positive and negative exercise ECG and exercise echocardiographic results to predict the presence or absence of myocardial vascular compromise. Differences between the techniques were assessed by the chi-square test. In addition, we evaluated the ability of exercise echocardiography to detect not only the presence but also the location and extent of myocardial vascular compromise. We divided the left ventricle into anterior, posterolateral and inferior regions corresponding approximately to the areas supplied by, respectively, the left anterior descending, left circumflex and right coronary arteries. We then assessed the ability of exercise echocardiography to detect vascular compromise in one and in more than one region.

Results

The results of exercise electrocardiography were positive in 93 cases, negative in 60 and inconclusive in 60 (Table 1).

The results of exercise echocardiography were positive for ischemia in 109 cases and negative in 84. There were 20 inconclusive studies, including 14 studies without new or worsening wall motion abnormalities in which the target heart rate of 85% was not achieved and 6 studies in which the image was not of sufficient quality to allow analysis. Of the 109 exercise echocardiograms with positive findings, 52 predicted ischemia of one region, 51 of two regions and 6 of three regions.

Of the 213 coronary angiograms, 95 indicated adequate and 118 indicated compromised vascular supply. The compromise involved one region in 67 cases, two regions in 46 and three regions in 5. In total, there were 174 areas of vascular compromise in 118 cases; 53 of these areas were in the anterior, 41 in the inferior and 80 in the posterolateral region.

Table 2 compares the positive predictive values of exercise echocardiography and those of exercise electrocardiography. The exercise ECG results did not correlate well with those of angiography. In >30% of cases with positive exercise ECG findings, the angiogram indicated a totally adequate vascular supply, whereas in almost 50% of cases with negative exercise ECG findings, angiography indicated a compromised vascular supply.

Table 2. Comparison of Exercise Electrocardiographic and Echocardiographic Results

Exercise Study	Inconclusive Tests	Positive Predictive Value	Negative Predictive Value
Electrocardiogram	60/213 (28%)	58/93 (62%)	31/60 (52%)
Echocardiogram	20/213 (9%)	93/109 (85%)	68/84 (81%)
p value	< 0.001	< 0.001	< 0.001

The greater the number of abnormal regions on the exercise echocardiogram, the more likely was vascular compromise on the angiogram. Table 3 demonstrates that an exercise echocardiogram that showed abnormality in two or three regions was associated with abnormal angiographic findings in 98% of cases.

Of the 16 exercise echocardiograms with false positive results, 15 predicted ischemia in only one region. All false positive findings occurred in areas with wall motion abnormalities at rest. There were no false positive results in echocardiograms that showed no wall motion abnormality at rest. The false positive findings were distributed equally among regions: anterior in 6 cases, inferior in 7 and posterolateral in 4.

Of the 16 exercise echocardiograms with false negative findings, 14 were associated with angiograms that demonstrated vascular compromise in only one region. The two others were associated with compromise in two regions. Of the 18 regions with false negative echocardiographic findings, only 2 were anterior and 3 inferior, whereas 13 were posterolateral.

Patients manifested symptoms in 52 cases (<25%). In 17 of these 52 cases, the patient had adequate vascular supply on angiography. In the symptomatic patients, the positive predictive value of the exercise echocardiogram was 87% and the negative predictive value 88%; these values were not statistically different from those in the group without symptoms.

Discussion

Exercise echocardiography clearly has a role in the evaluation of patients with coronary artery disease (5–10). It is accurate, reliable and relatively inexpensive. However, its application in patients after bypass surgery has the theoretic disadvantage that many of these patients have segmental wall motion abnormalities at rest that may confound interpretation of the ultrasound data. Despite these concerns, both Sawada et al. (11) and Crouse et al. (12), in smaller groups of patients, showed good predictive accuracy of the exercise echocardiogram. Although image quality after exercise was a concern in the past (13,14), <3% of our echocardiograms were considered uninterpretable because of image quality. Like the study of Crouse et al. (12), our study demonstrated the poor correlation of exercise electrocardiographic findings with compromised vascular supply. However, in contrast to their study, many of our patients were asymptomatic and 45% had full and adequate revascularization, whereas only 10% of the 125 patients in their study had adequate vascular supply.

Table 3. Comparison of Exercise Echocardiographic and Angiographic Findings

Exercise Echocardiogram		Angiogram		Predictive Values	
Findings	No.	Findings	No.	Negative	Positive
Normal	84	Stenosis			
		0–50%	68	81%	
		≥50%	16		
Abnormality of one region	52	Stenosis			
		0–50%	15		71%*
		≥50%	37		
Abnormality of two or three regions	57	Stenosis			
		0–50%	1		98%*
		≥50%	56		

*p < 0.005. Note that the likelihood of finding vascular compromise on angiography is related to the number of abnormal regions on exercise echocardiography.

False positive, false negative and inconclusive studies. All false positive exercise echocardiographic findings involved areas of wall motion abnormality at rest. Significantly, in 15 of the 16 studies, findings were considered positive in one region only. Only one exercise echocardiogram with a false positive result predicted ischemia in two regions (Table 3). We had expected that the abnormal septal motion seen commonly after bypass surgery might cause errors in echocardiographic interpretation. However, the presence of abnormal septal motion did not add to the frequency of false positive results in the anterior region.

There were 16 echocardiograms with false negative results. At angiography, 14 of these 16 cases were compatible with vascular compromise of one region and the other 2 cases with involvement of two regions. The majority of areas with false negative findings were posterolateral. This preponderance of false negative findings in the posterolateral region may reflect our inability to always be certain of the motion in the posterolateral region. As well, failure to detect ischemia in patients with 50% stenoses may not necessarily indicate a shortcoming in the technique. It may well be that in these cases the lesion simply did not produce ischemia sufficient to compromise wall motion (5,6,10). Our study relied on the visual angiographic assessment of lesions, and we agree with Roger et al. (15) that there are limitations to the angiographic prediction of the physiologic stenosis in an artery or graft. Despite those limitations, angiography continues to be the most widely used technique in the clinical setting and allows us to translate these results into everyday clinical practice.

There were 20 inconclusive exercise echocardiographic tests: 6 because the image quality was poor and 14 because the tests were submaximal and showed no new or worsening abnormalities after exercise. The target heart rate of 85% had been our standard for exercise electrocardiography. However, there is some question as to the importance of reaching this target rate (10,16). In a study of patients after angioplasty, Aboul-Enein et al. (16) demonstrated that neither the sensitivity nor the specificity of symptom-limited exercise echocardiography was significantly affected by the degree of effort during exercise. However, Marwick et al. (10) showed that

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sensitivity could be increased by excluding patients with a heart rate <85% of predicted maximum. Ten of our 14 patients who did not reach target heart rate and had no exercise-induced echocardiographic abnormalities at their final heart rate had no evidence of vascular compromise on angiography.

In 93 of the 118 cases with vascular compromise on angiography, the results of exercise echocardiography were abnormal (sensitivity 79%). In 78 of the 95 cases without evidence of vascular compromise on angiography, the exercise echocardiographic result was not abnormal (specificity 82%). Significantly, the greater the number of regions affected by vascular compromise on angiography, the more likely was an abnormal finding on exercise echocardiography. Of the 67 angiograms showing compromise of one region, 46 were associated with abnormal findings on exercise echocardiography (sensitivity 69%), whereas the 51 angiograms showing vascular compromise of two or three regions were accompanied by 47 exercise echocardiograms with abnormal findings (sensitivity 92%). After excluding cases with a nondiagnostic exercise echocardiogram, the sensitivity for compromise of one region became 77% (46 of 60) and that for compromise of multiple regions became 96% (47 of 49); these results are similar to those reported by Marwick et al. (10).

Identification of extent of vascular compromise. Recently, Roger et al. (15) demonstrated, in patients without previous bypass surgery, the ability of exercise echocardiography to identify multivessel coronary artery disease with a sensitivity of 73% and specificity of 70%. Of the 51 patients in our study who had multiregion involvement on angiography, 35 had abnormal exercise echocardiographic findings in two or three regions (sensitivity 69%). Among the 162 patients whose coronary angiogram showed either no vascular compromise or compromise in only one region, the exercise echocardiograms of 122 showed either normal findings or no more than one region of abnormality (specificity 75%). This capability of exercise echocardiography to differentiate patients with multiple regions of vascular compromise appears to be unchanged after bypass surgery and offers the clinician an important advantage in making decisions on the performance of angiography.

Exercise response of rest abnormalities. There have been some concerns about accepting as evidence of ischemia the failure of a hypokinetic segment to increase motion after exercise despite adequate heart rate. Quinones et al. (9) have pointed out the difficulties in differenting ischemia from scar with the use of exercise echocardiography. An akinetic or dyskinetic segment on the rest echocardiogram is almost always evidence of infarction. However, if there is some motion and some thickening of that segment, it is classified as hypokinetic. Any segment with thickening myocardium, albeit reduced thickening, contains some live muscle, and failure of that live muscle to augment its motion can be considered as abnormal as the failure of a normal rest segment to become hyperdynamic. We have used this criterion, as well as worsening of motion, to define the abnormal response of a hypokinetic segment to exercise. If we reanalyze our results to exclude this criterion, we find a decrease in the number of false positive echocardiograms and a higher overall specificity of 91% but lower overall sensitivity of 72% to predict the presence of any vascular compromise on subsequent angiography.

Conclusions. Exercise echocardiography has been demonstrated to be of value in screening for coronary artery disease (6–10,14) and in the follow-up of patients after coronary angioplasty (16–19). This study has confirmed that exercise echocardiography can also be a reliable predictor of the presence or absence of compromised vascular supply after bypass surgery. Fewer than 3% of our tests could not be interpreted because of image quality. Although there was a false positive rate of 15%, >90% of the tests with false positive results had predicted ischemia of only one region. Exercise echocardiograms with positive findings in two or three regions had a false positive rate of <2%. Because of the special prognostic significance of left anterior descending artery graft disease after bypass surgery, it is clinically important that only 2 of the 18 regions with false negative findings involved the anterior wall.

In this study, exercise echocardiography demonstrated the ability to detect vascular compromise in patients after coronary bypass surgery and to identify those with involvement of multiple regions. As shown in other patient groups (20), we found exercise echocardiography to be clearly superior to exercise electrocardiography in predicting the presence and extent of myocardial vascular compromise. Our results indicate that we can be confident in applying exercise echocardiography to a wide range of patients after bypass surgery and that it will help us better direct our therapy and select those patients who will most benefit from coronary angiography.

References

1. FitzGibbon GM, Leach AJ, Kafka HP, Keon WJ. Coronary bypass graft fate: long-term angiographic study. J Am Coll Cardiol 1991;17:1075–80.
2. FitzGibbon GM, Leach AJ, Keon WJ, Burton JR, Kafka HP. coronary bypass graft fate: angiographic study of 1179 vein grafts early, one year and five years after operation. J Thorac Cardiovasc Surg 1986;91:773–8.
3. Ahnve S, Savvides M, Abouantoum S, Atwood JE, Froelicher V. Can myocardial ischemia be recognized by the exercise electrocardiogram in coronary disease patients with abnormal resting Q waves? Am Heart J 1986;111:909–16.
4. Meyers DG, Bendon KA, Hankins JH, Stratbucker RA. The effect of baseline electrocardiographic abnormalities on the diagnostic accuracy of exercise-induced ST segment changes. Am Heart J 1990;119:272–6.
5. Sheikh KH, Bengtson JR, Helmy S, et al. Relation of quantitative coronary lesion measurements to the development of exercise-induced ischemia assessed by exercise echocardiography. J Am Coll Cardiol 1990;15:1043–51.
6. Vandenberg BF, Fleagle SR, Skorton DJ. Exercise echocardiography and quantitative angiography: improved identification of physiologically significant coronary artery stenoses. J Am Coll Cardiol 1990;15:1052–4.
7. Crouse LJ, Harbercht JJ, Vacek JL, Rosamond TL, Cramer PH. Exercise echocardiography as a screening test for coronary artery disease and correlation with coronary arteriography. Am J Cardiol 1991;67:1213–8.
8. Oberman A, Fan PH, Nanda NC, et al. Reproducibility of two-dimensional exercise echocardiography. J Am Coll Cardiol 1989;14:923–8.
9. Quinones MA, Verani MS, Haichin RM, Mahmarian JJ, Suarez J, Zoghbi WA. Exercise echocardiography versus 201-Tl single-photon emission computed tomography in evaluation of coronary artery disease: analysis of 292 patients. Circulation 1992;85:1026–31.
10. Marwick TH, Nemec JJ, Pashkow FJ, Stewart WJ, Salcedo EE. Accuracy and limitations of exercise echocardiography in a routine clinical setting. J Am Coll Cardiol 1992;19:74–81.

11. Sawada SG, Judson WE, Ryan T, Armstrong WF, Feigenbaum H. Upright bicycle exercise echocardiography after coronary artery bypass grafting. Am J Cardiol 1989;64:1123–9.
12. Crouse LJ, Vacek JL, Beauchamp GD, Porter CB, Rosamond TL, Kramer PH. Exercise echocardiography after coronary artery bypass grafting. Am J Cardiol 1992;70:572–6.
13. Armstrong WF. Stress echocardiography for detection of coronary artery disease. Circulation 1991;84:I-43–9.
14. Ryan T, Feigenbaum H. Exercise echocardiography. Am J Cardiol 1992;69: 82H–9H.
15. Roger VL, Pellikka PA, Oh JK, Bailey KR, Tajik AJ. Identification of multivessel coronary artery disease by exercise echocardiography. J Am Coll Cardiol 1994;24:109–14.
16. Aboul-Enein H, Bengtson JR, Adams DB, et al. Effect of the degree of effort on exercise echocardiography for the detection of restenosis after coronary artery angioplasty. Am Heart J 1991;122:430–7.
17. Labovitz AJ. Exercise echocardiography after coronary angioplasty: expanding applications. J Am Coll Cardiol 1990;15:600–1.
18. Broderick T, Sawada S, Armstrong WF, et al. Improvement in rest and exercise-induced wall motion abnormalities after coronary angioplasty: an exercise echocardiographic study. J Am Coll Cardiol 1990;15:591–9.
19. Mertes H, Erbel R, Nixdorff U, Mohr-Kahaly S, Kruger S, Jurgen M. Exercise echocardiography for the evaluation of patients after nonsurgical coronary artery revascularization. J Am Coll Cardiol 1993;21:1087–93.
20. Crouse LJ, Kramer PH. Exercise echocardiography: coming of age. J Am Coll Cardiol 1994;24:115–6.