IMPROVED DETECTION OF CORONARY ARTERY DISEASE BY EXERCISE ELECTROCARDIOGRAPHY WITH THE USE OF RIGHT PRECORDIAL LEADS

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ABSTRACT

Background Exercise electrocardiography is an imperfect test for the detection of coronary artery disease. We attempted to improve the diagnostic accuracy of exercise testing as a noninvasive method for the detection of coronary artery disease by using a combination of the left and right precordial leads.

Methods We studied 245 patients (218 men and 27 women) ranging from 32 to 74 years of age (mean [±SD], 52±8) who underwent treadmill exercise testing, thallium-201 scintigraphy, and coronary arteriography. During exercise testing, each patient had one electrocardiogram recorded with the standard 12 leads and 3 right precordial leads (V_3R, V_4R, and V_5R), with the results for each set of leads recorded and analyzed separately.

Results On the basis of coronary arteriography, 34 patients had normal coronary arteries, 85 had single-vessel disease, 84 had two-vessel disease, and 42 had three-vessel disease. The sensitivities of the standard 12-lead exercise electrocardiogram, exercise electrocardiography incorporating right precordial leads, and thallium-201 scintigraphy were 52 percent, 89 percent, and 87 percent, respectively, for the detection of single-vessel disease; 71 percent, 94 percent, and 96 percent for the detection of two-vessel disease; 83 percent, 95 percent, and 98 percent for the detection of three-vessel disease; and 66 percent, 92 percent, and 93 percent for the detection of any coronary artery disease. The specificities of the three methods for the detection of any coronary artery disease were 88 percent, 88 percent, and 82 percent, respectively.

Conclusions Use of right precordial leads along with the standard six left precordial leads during exercise electrocardiography greatly improves the sensitivity of exercise testing for the diagnosis of coronary artery disease. (N Engl J Med 1999;340:340-5.)

EXERCISE electrocardiography is frequently used as a diagnostic test for coronary artery disease. Previous studies correlating exercise-induced ST-segment depression with findings on coronary arteriography and thallium-201 scintigraphy have provided information on the reliability of exercise testing. The sensitivity of standard exercise testing for the detection of single-vessel coronary artery disease is low, ranging from 35 to 61 percent in various studies.[1-5] Its sensitivity for the detection of right coronary artery disease is even lower. ST-segment elevation in the right precordial leads V_3R through V_7R during percutaneous transluminal coronary angioplasty might indicate stenosis in the right coronary artery.[6] Several studies that used recordings from the V_4R lead during exercise testing reported a small improvement in the detection of right coronary artery disease.[7,8]

We assessed whether the use of the right precordial leads V_3R, V_4R, and V_5R along with the left precordial leads improved the sensitivity of exercise testing in the detection of coronary artery disease.

METHODS

Selection of Patients

From a total of 268 consecutive patients who were referred to our hospital with symptoms resembling angina, 245 (218 men and 27 women) were studied. All patients included in the study underwent coronary arteriography within two months after a maximal treadmill exercise test with electrocardiography incorporating right precordial leads and thallium-201 scintigraphy. The 23 patients who refused to undergo coronary arteriography were not included in the study. The mean (±SD) age of the patients was 52±8 years (range, 32 to 74). Eighteen patients (7 percent) had arterial hypertension (systolic blood pressure of at least 140 mm Hg, diastolic blood pressure of at least 90 mm Hg, or both), 12 (5 percent) had diabetes mellitus, 54 (22 percent) had hypercholesterolemia, 22 (9 percent) were obese (body-mass index [the weight in kilograms divided by the square of the height in meters] of more than 27), and 68 (28 percent) were smokers.

Excluded from the study were patients who had left or right bundle-branch block, left or right ventricular hypertrophy, ventricular preexcitation, a history of myocardial infarction, or valvular or congenital heart disease; those who had undergone aortocoronary bypass surgery or coronary angioplasty; and those who were receiving digitalis. The study was approved by the ethics committee of our hospital, and written informed consent was obtained from all participants.

Exercise Testing

All patients exercised on Quinton 5000 treadmill systems (Quinton Instruments, Bothell, Wash.) according to the multistage Bruce protocol. Each patient underwent exercise testing and had an electrocardiogram recorded with the standard 12 leads and 3 right precordial leads (V_3R, V_4R, and V_5R); the results for each set of leads were recorded and analyzed separately. The electrocardiograms were recorded continuously during exercise and for up to 10 minutes during the recovery period. All medications were discontinued at a time that allowed at least five half-lives to elapse

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before exercise testing. The positions of the left and right precordial leads were as previously described.[9] Blood pressure was measured by sphygmomanometry every two minutes during exercise. Exercise was terminated whenever a patient had severe angina, fatigue, dyspnea, or arrhythmias. If none of these symptoms occurred, testing was terminated on the appearance of 3-mm ST-segment depression, 2-mm ST-segment elevation, or a decrease in systolic blood pressure of 20 mm Hg or more.

Exercise-induced ischemic ST-segment changes in the standard 12 leads, the right precordial leads, or both were defined as a horizontal or downsloping ST-segment depression of at least 1 mm 60 msec after the J point; upsloping ST segment with a depression of at least 1.5 mm 80 msec after the J point; in the presence of ST-segment depression at rest, an additional 2 mm of ST-segment depression[10,11]; or an ST-segment elevation of at least 1 mm at the J point as compared with the base-line electrocardiogram recorded at rest.

The exercise electrocardiogram was considered to be negative for ischemia when the heart rate reached at least 85 percent of the maximal predicted value in the absence of ischemic ST-segment changes. Exercise electrocardiograms without ischemic ST-segment changes, which were terminated when the heart rate was less than 85 percent of the predicted maximal rate, were considered inconclusive. Patients with inconclusive exercise tests were excluded from the study. Measurements on the electrocardiograms were made by two of the investigators using magnifying lenses; the investigators were unaware of the results of angiography and thallium-201 scintigraphy. The respective intraobserver and interobserver variations were 0.08±0.06 mm and 0.09±0.05 mm (correlation coefficients, 0.98 and 0.99) for ST-segment depression and 0.06±0.04 mm and 0.07±0.03 mm (correlation coefficients, 0.98 and 0.98) for ST-segment elevation. Disagreements between observers, which occurred in 11 cases, were resolved by a third interpreter.

Thallium-201 Single-Photon-Emission Computed Tomography

Tomographic thallium-201 scintigraphy was performed in all patients. At peak exercise, 2 mCi (74 MBq) of thallium-201 was administered intravenously, and patients continued to exercise for an additional 45 to 60 seconds. Thallium images were then obtained with a high-sensitivity, low-energy, medium-resolution, parallel-hole collimator (model 400 AC/T, General Electric, Milwaukee) centered on the 68-keV photo peak with a 20 percent window. The camera was rotated 180 degrees in an elliptical orbit around the patient's thorax from a right anterior oblique angle of 40 degrees to a left posterior angle of 40 degrees, in 6-degree increments lasting 30 seconds each. Redistribution images were obtained three to four hours after exercise testing while the patients were resting. From the raw scintigraphic data, vertical short-axis and vertical and horizontal long-axis tomograms were reconstructed, and four consecutive representative slices of each view were selected for interpretation. The reconstructed stress and redistribution images were then analyzed both qualitatively and quantitatively by standard techniques.[12] The results were interpreted independently by two investigators who had no knowledge of the exercise and catheterization data.

Coronary Arteriography and Left Ventriculography

All patients underwent left ventriculography in the 30-degree right anterior oblique projection and selective coronary arteriography according to the percutaneous (Judkins) technique. Clinically significant coronary artery disease was diagnosed when there was a narrowing of 70 percent or more of the diameter of the lumen in the left anterior descending, left circumflex, or right coronary artery or narrowing of 50 percent or more of the diameter of the lumen in the left main coronary artery. The investigators in the catheterization laboratory were unaware of the results of exercise testing and thallium-201 scintigraphy.

Statistical Analysis

Values are expressed as means ±SD. The McNemar chi-square test for paired data was used to detect associations between different observations in the same patient (the technique incorporating right precordial leads was compared with standard exercise electrocardiography and with thallium-201 scintigraphy). The significance of the differences between exercise measurements in the subgroups of the study population (patients with coronary artery disease and those with normal coronary arteries) was tested by two-way analysis of variance. P values of 0.05 or less were considered to indicate statistical significance. Statistical analyses were performed with SPSS statistical software (version 8.0; SPSS, Chicago).

RESULTS

The results of exercise testing are presented in Table 1. A total of 78 patients with coronary artery disease had angina during exercise. Nineteen patients stopped exercising because of worsening angina. All of them had ST-segment changes on the electrocardiogram. According to the data from catheterization,

TABLE 1. ELECTROCARDIOGRAPHIC VARIABLES DURING EXERCISE.*

MEASUREMENT	PATIENTS WITH CORONARY ARTERY DISEASE	PATIENTS WITH NORMAL CORONARY ARTERIES	P VALUE
Duration of exercise — sec	520±74	650±63	<0.001
Standard exercise testing (12 leads) — mm			
Maximal ST-segment depression	2.3±0.6	0.7±0.2	<0.001
Maximal ST-segment elevation	1.6±0.7	0.3±0.2	<0.001
Testing with right precordial leads			
Maximal ST-segment elevation — mm	1.4±0.3	0.3±0.1	<0.001
Maximal ST-segment depression — mm	1.2±0.3	0.2±0.1	<0.001
Time to ST-segment changes of 1 mm — sec	380±32	620±20	<0.001
Maximal systolic blood pressure — mm Hg	184±25	195±16	0.11
Maximal heart rate — beats/min	156±10	168±15	0.13
Patients with exercise-induced angina — no./total no. (%)	78/211 (37)	2/34 (6)	<0.001

*Plus–minus values are means ±SD.

34 of the 245 patients (14 percent) had normal coronary arteries, whereas 85 patients (35 percent) had single-vessel disease, 84 (34 percent) had two-vessel disease, and 42 (17 percent) had three-vessel disease. Of the 34 patients considered to have normal coronary arteries, 25 had no detectable narrowing of the arteries, 6 had stenoses of less than 50 percent of the diameter of the vessel, and the remaining 3 had stenoses of 50 to 69 percent. All three patients with stenoses of 50 to 69 percent had negative results on exercise tests and thallium-201 scintigraphy. Among the patients with single-vessel disease, 35 (41 percent) had disease of the left anterior descending coronary artery, 28 (33 percent) had disease of the right coronary artery, and 22 (26 percent) had disease of the left circumflex coronary artery. Table 2 shows the sensitivity for the detection of coronary artery disease of ST-segment changes on the standard 12-lead electrocardiogram, on the electrocardiogram with the right precordial leads, and on the electrocardiogram with both sets of leads.

In comparison with the standard 12-lead exercise electrocardiogram, the electrocardiogram incorporating the right precordial leads increased sensitivity for the detection of single-vessel disease from 52 percent (44 of 85 patients) to 89 percent (76 of 85), increased sensitivity for the detection of two-vessel disease from 71 percent (60 of 84) to 94 percent (79 of 84), increased sensitivity for the detection of three-vessel disease from 83 percent (35 of 42) to 95 percent (40 of 42), and increased sensitivity for the detection of any coronary artery disease from 66 percent (139 of 211) to 92 percent (195 of 211) (Table 2 and Fig. 1). In comparison with the standard 12-lead exercise electrocardiogram, the electrocardiogram incorporating the right precordial leads increased the sensitivity for the detection of disease in the left anterior descending coronary artery from 77 percent to 91 percent, of disease in the right coronary artery from 25 percent to 89 percent, and of disease in the left circumflex coronary artery from 45 percent to 86 percent (Table 2). In other words, the standard 12-lead exercise electrocardiogram, which does not include the right precordial leads, failed to detect disease in the left anterior descending coronary artery in 14 percent of the patients, disease in the right coronary artery in 64 percent of the patients, and disease in the left circumflex coronary artery in 41 percent of the patients in whom electrocardiography incorporating the right precordial leads succeeded in detecting the narrowed coronary vessel. Furthermore, although our study was not specifically designed to evaluate results in men and women separately, we observed that in the limited number of

TABLE 2. SENSITIVITY OF ST-SEGMENT CHANGES ON STANDARD 12-LEAD EXERCISE ELECTROCARDIOGRAPHY AND ON EXERCISE ELECTROCARDIOGRAPHY INCORPORATING 3 RIGHT PRECORDIAL LEADS FOR THE DETECTION OF CORONARY ARTERY DISEASE.

TYPE OF DISEASE AND ARTERIES INVOLVED*	NO. OF PATIENTS	ST-SEGMENT CHANGES					P VALUE§
		RIGHT PRECORDIAL LEADS ONLY	STANDARD 12 LEADS ONLY	BOTH RIGHT PRECORDIAL AND STANDARD 12 LEADS	STANDARD 12 LEADS†	NEW TECHNIQUE‡	
		percent sensitivity (no. with changes)					
Single-vessel disease	85	38 (32)	44 (37)	8 (7)	52 (44)	89 (76)	<0.001
LAD	35	14 (5)	69 (24)	9 (3)	77 (27)	91 (32)	0.06
RCA	28	64 (18)	18 (5)	7 (2)	25 (7)	89 (25)	<0.001
LCX	22	41 (9)	36 (8)	9 (2)	45 (10)	86 (19)	0.004
Two-vessel disease	84	23 (19)	49 (41)	23 (19)	71 (60)	94 (79)	<0.001
LAD + RCA	30	23 (7)	50 (15)	23 (7)	73 (22)	97 (29)	0.02
LAD + LCX	26	12 (3)	62 (16)	15 (4)	77 (20)	88 (23)	0.25
RCA + LCX	28	32 (9)	36 (10)	29 (8)	64 (18)	96 (27)	0.004
Three-vessel disease	42	12 (5)	43 (18)	40 (17)	83 (35)	95 (40)	0.06
All cases of coronary artery disease	211	27 (56)	45 (96)	20 (43)	66 (139)	92 (195)	<0.001

*LAD denotes left anterior descending coronary artery, RCA right coronary artery, and LCX left circumflex coronary artery.

†The values in this column are the sum of those in the columns titled "standard 12 leads only" and "both right precordial and standard 12 leads." Because of rounding, not all rows sum to the totals shown.

‡The values in this column are the sum of those in the columns titled "right precordial leads only," "standard 12 leads only," and "both right precordial and standard 12 leads." Because of rounding, not all rows sum to the totals shown.

§P values are for the comparison of "standard 12 leads" with "new technique."

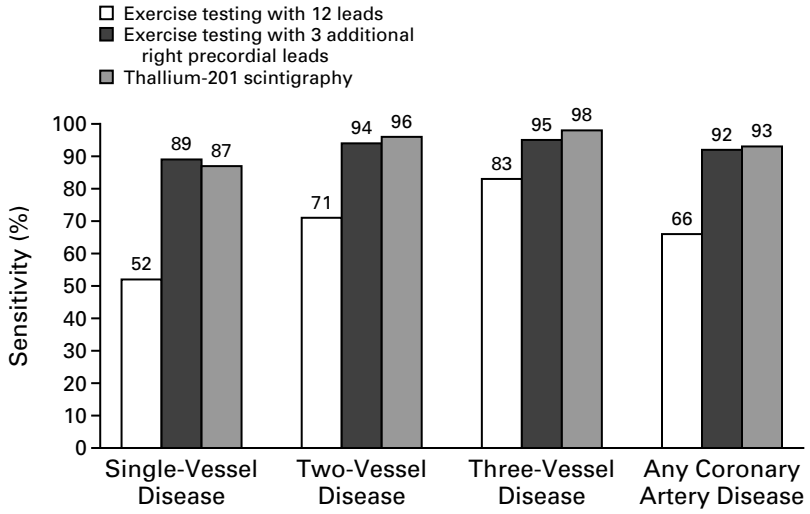

Figure 1. Sensitivity of Standard Exercise Testing with the 12-Lead Electrocardiogram, Exercise Testing with the Addition of 3 Right Precordial Leads, and Thallium-201 Scintigraphy for the Detection of Single-, Two-, and Three-Vessel Coronary Artery Disease and of Any Coronary Artery Disease.

women in the study, the addition of the right precordial leads improved the sensitivity of exercise electrocardiography from 71 percent (12 of 17 patients) to 88 percent (15 of 17) without affecting the specificity (80 percent).

The respective values for the sensitivity of our new technique and thallium-201 scintigraphy were 89 percent (76 of 85 patients) and 87 percent (74 of 85) for the detection of single-vessel coronary artery disease, 94 percent (79 of 84) and 96 percent (81 of 84) for two-vessel disease, 95 percent (40 of 42) and 98 percent (41 of 42) for three-vessel disease, and 92 percent (195 of 211) and 93 percent (196 of 211) for any coronary artery disease (Fig. 1). None of these differences were statistically significant. For single-vessel disease, the respective sensitivities of our technique and thallium-201 scintigraphy were 91 percent (32 of 35 patients) and 94 percent (33 of 35) for the detection of disease in the left anterior descending coronary artery, 89 percent (25 of 28) and 75 percent (21 of 28) for disease in the right coronary artery, and 86 percent (19 of 22) and 91 percent (20 of 22) for disease in the left circumflex coronary artery. Again, none of these differences were statistically significant.

The specificity of both conventional 12-lead exercise electrocardiography and exercise electrocardiography with the addition of the right precordial leads for the detection of coronary artery disease was 88 percent (30 of 34 patients). Neither the specificity of the standard 12-lead exercise electrocardiogram nor the specificity of the electrocardiogram with the right precordial leads was significantly different from the specificity of thallium-201 scintigraphy, which was 82 percent (28 of 34 patients).

DISCUSSION

The principal finding of this study was that a new technique of exercise testing that combines data on ST-segment changes from both the left and the right precordial leads provided excellent sensitivity for the detection of coronary artery disease, similar to that of thallium-201 scintigraphy. The new technique significantly improved the ability of the standard 12-lead exercise electrocardiogram to detect single-vessel coronary artery disease, especially clinically significant stenosis of the right coronary artery and the left circumflex coronary artery.

ST-segment elevation in the right precordial leads during evolving inferior myocardial infarction indicates right ventricular involvement.[13,14] It has been suggested that ST-segment deviation in the right precordial leads V_3R through V_7R during transluminal coronary angioplasty can identify the presence of right coronary-artery stenosis.[6] ST-segment elevation of at least 1 mm in the V_4R lead had a sensitivity of 100 percent and a specificity of 87 percent for detection of proximal occlusion of the right coronary artery.[13] The V_4R lead has also been used in exercise testing to predict proximal right coronary artery disease.[7,8] Braat et al.[8] reported a sensitivity of 56 percent and a specificity of 96 percent for the diagnosis of proximal right coronary artery disease on the basis of ST-segment deviation in the V_4R lead during exercise testing. In a study by Chouhan et al.,[7] the sensitivity and specificity of the V_4R lead in diagnosing right coronary artery disease were 32 percent and 88 percent, respectively, whereas the combination of the V_4R lead with the standard 12 electrocardiographic leads increased the sensitivity of the exercise electrocardiogram in diagnosing coronary ar-

tery disease from 56 percent to 65 percent without affecting the specificity (79 percent). On the other hand, the presence of exercise-induced ST-segment elevation in lead V_1 in patients with proximal right coronary artery stenosis[15] and the presence of ST-segment elevations in the right precordial leads in patients with occlusions of the left anterior descending coronary artery[16] have already been described.

In our study, we recorded the electrocardiographic data from 3 right precordial leads, V_3R, V_4R, and V_5R, in combination with the standard 12 leads. The contribution of the three right precordial leads to the detection of single-vessel coronary artery disease and to the identification of the diseased vessel was prominent for both right coronary-artery stenosis and disease of the left circumflex coronary artery. Furthermore, we noticed that exercise-induced ST-segment changes in V_3R, V_4R, or both, but not in V_5R, may identify right coronary-artery stenosis, whereas exercise-induced ST-segment changes in V_4R, V_5R, or both, but not in V_3R, may identify disease of the left circumflex coronary artery.

A meta-analysis of 150 studies revealed that exercise-induced ST-segment alterations identified coronary artery disease with a mean sensitivity of 68 ± 16 percent and a mean specificity of 77 ± 17 percent.[3] In our study, both the sensitivity and the specificity of the standard exercise electrocardiogram for the detection of coronary artery disease were in agreement with those previously reported. Our technique, which combined data from 3 right precordial leads with those from the standard 12 leads, significantly improved sensitivity without affecting specificity.

Previous studies reported values for sensitivity in the detection of single-vessel, two-vessel, and three-vessel coronary artery disease ranging from 35 to 40 percent, 62 to 67 percent, and 73 to 86 percent, respectively.[1,4,17] We found similar results with standard 12-lead exercise electrocardiography. The addition of the right precordial leads significantly improved the sensitivity of the electrocardiogram for the detection of coronary artery disease, especially for the detection of single-vessel and two-vessel disease (Table 2). Other studies have suggested that single-vessel disease is frequently associated with false negative exercise tests, not only in the case of stenosis of the right coronary artery or left circumflex coronary artery,[5] but also in the case of stenosis of the left anterior descending coronary artery. The sensitivity of the standard 12-lead exercise electrocardiogram for the detection of single-vessel disease in the right coronary artery or left circumflex coronary artery was significantly improved with our technique. Moreover, there was a trend toward improvement in the sensitivity of the standard 12-lead test for the detection of single-vessel disease in the left anterior descending coronary artery when the 3 right precordial leads were added (Table 2). Thus, our technique succeeded in detecting single-vessel disease of the left anterior descending coronary artery, the right coronary artery, and the left circumflex coronary artery in 14 percent, 64 percent, and 41 percent of the patients, respectively, in whom the standard 12-lead exercise test failed to detect disease.

Tomographic thallium-201 scintigraphy has been recommended as a highly accurate method, with excellent sensitivity (around 90 percent) and specificity (around 70 percent) for the diagnosis of coronary artery disease.[18-23] The sensitivity of tomographic thallium-201 scintigraphy for the detection of single-vessel, two-vessel, and three-vessel coronary artery disease was 83 percent, 93 percent, and 95 percent, respectively.[18-20,23] Finally, the respective sensitivity and specificity of tomographic thallium-201 scintigraphy were 80 percent and 83 percent for the detection of disease of the left anterior descending coronary artery, 72 percent and 84 percent for disease of the left circumflex coronary artery, and 83 percent and 84 percent for disease of the right coronary artery.[18-23]

The sensitivity of our new technique for the detection of single-vessel, two-vessel, three-vessel, and all coronary artery disease was similar to that of thallium-201 scintigraphy (Fig. 1). Furthermore, the sensitivity of our new technique was similar to that of thallium-201 scintigraphy for the detection of disease of the left anterior descending coronary artery, right coronary artery, and left circumflex coronary artery.

We conclude that exercise electrocardiography in which a combination of left and right precordial leads is used has excellent sensitivity in the detection of coronary artery disease. This approach is widely available, low in cost, and highly accurate and may improve the diagnosis of coronary artery disease.

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