Improved Efficiency of Treadmill Exercise Testing Using a Multiple Lead ECG System and Basic Hemodynamic Exercise Response

BERNARD R. CHAITMAN, M.D., MARTIAL G. BOURASSA, M.D., PIERRE WAGNIART, M.D., FREDERICO CORBARA, M.D., AND RONALD J. FERGUSON, PH.D.

SUMMARY One hundred consecutive men with a normal ECG at rest had a maximal treadmill test using 14 leads during and post-exercise. Coronary arteriography performed the following day revealed coronary stenoses ≥70% in 66 patients. Test results obtained from a V4 lead were compared to different lead combinations and were correlated with arteriographic findings. A positive exercise test occurred in 37 men using an isolated V4 lead compared to 50 men (P < 0.05) using 11 leads, 52 men (P < 0.05) using a combined CMV, CCx, CI (inferior) lead system and 58 (P < 0.001) men using all 14 leads. The predictive value of a positive test varied between 89-95% and was not changed significantly by the addition of multiple leads. The 14 lead ECG was positive in 43/45 (96%) patients with multivessel disease.

Parameters which helped to predict multivessel disease using 14 leads were 1) the time that ischemia first appeared, 2) the pressure-rate product at the time ischemia first appeared, and 3) the maximum workload that could be attained. In general, the magnitude of ST-segment depression and the time required for a positive ECG to return to normal postexercise were not useful predictors of multivessel disease.

We conclude that the use of multiple leads improves the sensitivity and efficiency of the maximal treadmill exercise test. The usefulness of exercise test results can be further improved if multiple leads are combined with physiologic data collected during exercise.

THE DIAGNOSTIC VALUE OF EXERCISE TESTING has been criticized and defended in recent editorials.1-3 Redwood and colleagues4 have argued that an increased incidence of false positive tests which occur in an asymptomatic population could result in a needless increase in the number of coronary arteriograms which are being performed. Several studies support his concern.4-6 In addition, these investigators state that a good clinical history alone is usually adequate in patients with typical angina pectoris and that exercise testing provides superfluous data. Sheffield et al.7 and McHenry8 have defended the value of exercise testing and state that the ECG response is only one of several parameters which should be examined during an exercise test and that the efficiency of this diagnostic procedure can be maximized if a multiple lead system is used. The optimal number of leads required to achieve maximal sensitivity without reducing the predictive value of a positive test has not been well studied. Therefore, we have compared several combinations of lead systems during exercise testing to coronary arteriographic findings in a consecutive series of 100 men who had a normal resting ECG and no previous history of myocardial infarction. Several physiologic responses to exercise such as treadmill endurance time, heart rate, and systolic blood pressure response, and the duration of exercise required to produce ST-segment depression were also studied to determine their usefulness as predictors of multivessel disease.

From the Division of Cardiology, Department of Medicine, Montreal Heart Institute, University of Montreal, Montreal, Quebec, Canada.

Supported in part by the J. L. Lévesque Foundation, Montreal, Canada, and the NHLI, CASS Study, Bethesda, Maryland.

During the period of this work, Dr. Pierre Wagniart was a visiting Fellow at the Montreal Heart Institute and Dr. Frederico Corbara held a research fellowship from the Art Council of Canada.

Address for reprints: Bernard R. Chaitman, M.D., Montreal Heart Institute, 5000 East, Belanger Street, Montreal, Quebec, Canada.

Received July 1, 1977; revision accepted August 19, 1977.

Methods

Patient Selection

Maximal treadmill tests were performed on 510 consecutive patients using a multiple lead system one day prior to a coronary arteriogram. From this population, 100 consecutive men who had a normal resting ECG and no clinical history of myocardial infarction were selected for further study. Their mean age was 49 (31–62) years. The indication for cardiac catheterization was nonspecific chest pain or atypical angina in 30 men and typical angina pectoris in 70 men; of the latter, 47 were Canadian Heart Anginal Class II and 23 were anginal class III.9 No patient had valvular heart disease or a cardiomyopathy. Cardiac medication except for sublingual nitroglycerin was stopped 2 weeks prior to the study in 85 patients; 15 had taken small doses of propranolol (<60 mg/day) one day prior to the treadmill test.

Exercise Protocol

Upright exercise on a motor-driven treadmill was performed following a modified Bruce protocol10 using a 3 min warm-up at 1.7 mph and a 5% grade. Cuff blood pressure measurements were obtained each minute throughout the test. The ECG was monitored continuously and recorded each minute during and for 5 minutes following exercise. All patients were in the fasting state and had not smoked for at least 2 hours prior to the test. Exercise was continued until exhaustion (43 men), severe dyspnea (7 men), or progressive angina (48 men) occurred. In two asymptomatic patients, the test was stopped because there was more than 3 mm of ST segment depression in one or more leads. All 36 patients with a negative test achieved ≥85% of their maximum age-predicted heart rate10 and 32 were able to achieve ≥90%.

Lead System

Arm and precordial electrodes were placed in the standard location recommended by Mason et al.10 Leg electrodes...
were placed posteriorly 1½–2 inches above the posterior iliac crest approximately 5 inches from the mid-line. In addition, a CM₅, CC₅ and CL (negative lead-manubrium; positive lead-left flank) lead were recorded. Siemens' exercise patient cable, ECG junction box, and nondisposable electrodes were used in conjunction with a Cambridge 3-channel direct-writing recorder (model 3038). The junction box was modified to accept input from the electrodes placed over the manubrium and right V₅ position. The X, Y, Z channel of the recorder was modified to register bipolar leads CM₅, CC₅, and CL. The 3 dB frequency response of the ECG amplifiers range from 0.05 to 100 Hzertz. Amplifier gain was set so that a 1 mV pulse produced a 10 mm deflection. Morphologic changes in aV₉ were not studied and our results are based on 14 leads.

The 14 lead ECG was recorded in the sitting and standing position before exercise, each minute during and just prior to stopping exercise, and in the sitting position immediately post-exercise and at 1, 3 and 5 minutes thereafter. At 2 and 4 min posttest, only CM₅, CC₅ and CL were recorded. The 14 leads were obtained as follows: leads I, II, III were recorded first followed by aV₁, aV₅, V₁, V₃, V₄, and CC₅, CM₅, CL. Each set of these leads were taken for 2.7 sec except for CC₅, CM₅, CL which were recorded for 6 sec.

The baseline from which observed changes were measured was taken from a line joining two consecutive P-Q junctions. The magnitude of ST segment depression was measured using a 7 power magnifying glass calibrated in tenths of a millimeter. Test results were reviewed by a second observer and differences were resolved by joint study of the record. The use of a calibrated magnifying glass substantially increased agreement between readers. Each exercise test was interpreted without knowledge of the coronary arteriographic results. The ECG criteria for a positive test in any lead were horizontal or downsloping ST-segment depression ≥1 mm for 0.08 sec or a slow upsloping ST segment depressed ≥2 mm, 0.08 sec after the J point in at least three consecutive complexes.

Coronary Arteriogram

Selective coronary arteriography was performed by a percutaneous transluminal approach using preformed catheters as previously described. Angulation views of each vessel were done routinely. Each coronary arteriogram was interpreted by an experienced cardiovascular radiologist unaware of the exercise test results. A stenosis ≥70% of the arterial intraluminal diameter was considered significant. A proximal stenosis of a large diagonal or marginal branch was considered as a stenosis of the left anterior descending or circumflex coronary artery respectively. In determining the extent of coronary disease, only dominant right coronary arteries were considered. Twenty-one patients had single vessel disease, 18 had two vessel disease, and 27 had three vessel disease. Three had a significant left main coronary lesion and 23 had a proximal left anterior descending arterial stenosis.

The left ventricle was opacified in the 30° right anterior oblique view before the arteriogram. Mean ejection fraction calculated by the area-length method was 0.61 ± 0.9 in 81 patients in whom this parameter could be calculated. Left ventricular wall motion was assessed using a fixed extra-cardiac reference system. There were no akinetic or dyskinetic left ventricular segments. Visual inspection of the left ventriculogram revealed moderate hypokinesis in 26 patients.

Analysis of Results

The unipolar V₉ lead was compared to bipolar leads CC₅ and CM₅ and to the following multiple lead systems: a) standard 11 lead ECG (excluding aV₉); b) three bipolar leads (CC₅, CM₅, CL), and c) to all 14 leads. The sensitivity, specificity, predictive values of a positive or negative test, and efficiency of the exercise test were determined for each lead system. Significant differences were analyzed by a Chi-square test.

Differences in treadmill endurance time and pressure-rate product (heart rate x systolic blood pressure) for varying extents of coronary disease were analyzed by a Student's t-test. Patients on propranolol the day before the exercise test were excluded from this analysis.

Results

Comparison of Single vs Multiple Leads (table 1)

Sensitivity

Results using a V₉ lead were compared to several combinations of lead systems. Of 66 patients with coronary disease, 37 had a positive exercise test in V₉ compared to 43 in CC₅ and 45 in CM₅. The incidence of positive tests increased to 50 (P < 0.05) using 11 leads, 52 (P < 0.05) using only the combination of CC₅, CM₅ and CL and 58 (P < 0.001) using

<table>
<thead>
<tr>
<th>Table 1. Comparison of V₉ to Other Lead Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single Leads</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sensitivity (TP/TP+FN)</td>
</tr>
<tr>
<td>Specificity (TN/TN+FP)</td>
</tr>
<tr>
<td>Predictive value of a positive test (TP/TP+FP)</td>
</tr>
<tr>
<td>Predictive value of a negative test (TN/TN+FN)</td>
</tr>
<tr>
<td>Efficiency (TP+TN/TP+TN+FP+FN)</td>
</tr>
</tbody>
</table>

* = P < 0.05; † = P < 0.001.

Abbreviations: TP = ECG positive; coronary disease present; FN = ECG negative; coronary disease present; TN = ECG negative; coronary disease negative; FP = ECG positive; coronary disease negative.
LEAD SYSTEM

FIGURE 1. The sensitivity of each lead system (except 14 leads) was increased when a slow upsloping ST segment depressed ≥ 2 mm, 0.08 sec after the J point was included among the criteria for a positive test. The specificity (not shown) remained unchanged.

all 14 leads. In addition, significantly more patients with coronary disease were detected using a 14 lead system than a single CMs or CC5 lead (P < 0.03).

The inclusion of a slow upsloping ST segment, depressed ≥ 2 mm, 0.08 sec after the J point, among the criteria for a positive test substantially increased the sensitivity of all lead systems except for the 14 lead ECG, where the sensitivity remained unchanged (fig. 1). There was always one lead in the 14 lead ECG which showed horizontal or downsloping ST-segment depression when a slow upsloping pattern was observed in another lead(s). The use of this criterion for positivity did not result in an increased number of false positives in any lead system.

The CMs, CC5, CL lead system was positive in eight patients in whom the 11 lead system was negative. The 11 lead system was positive in six patients in whom the CMs, CC5, CL lead system was negative; four of the six patients were positive in the V3 lead (fig. 2). Of 52 patients with a positive test using a CMs, CC5, CL system, the CMs lead was positive in nine cases where CC5 and CL were negative; the CC5 lead was positive in seven cases where CMs and CL were negative; and the CL lead was only positive once in the absence of a positive test in the CMs and CC5 leads (fig. 3). The recording of modified limb leads did not increase the sensitivity of the exercise ECG; positive changes in the limb leads were always accompanied by positive changes in the precordial leads and/or CMs, CC5 or CL.

Specificity

As illustrated in table 1, the use of multiple leads did not significantly change the number of exercise test results which remained negative when coronary disease was absent. The
slight increase in false positives which occurred using multiple leads did not result from the use of modified limb leads or the CL lead.

Predictive Value of the Exercise Test

Coronary disease was present in 89 to 95% of patients with a positive exercise test. The use of multiple leads did not decrease the predictive value of a positive test result. The predictive value of a negative test significantly increased using multiple leads compared to a V5 lead. Whereas a negative test using 14 leads was 78% accurate in confirming the absence of coronary disease, a single V5 lead was accurate only 52% of the time (P < 0.05).

Efficiency

Table 1 shows that multiple leads increase the efficiency of the exercise test. The 86% efficiency of the 14 lead ECG is significantly greater than the 69% efficiency of an isolated V5 lead (P < 0.05).

Determining the Extent of Coronary Disease

Sensitivity of the Method

Multivessel disease was associated with a higher incidence of positive test results than single vessel disease for each lead system used, as shown in figure 4. Of 21 patients with single vessel disease, nine (43%) had a positive test using V5 vs 15 (71%) using 14 leads (NS). A positive test using 14 leads occurred in all six men with an isolated left anterior descending stenosis, in 7/10 men with an isolated right coronary stenosis, and in 2/5 men with an isolated left circumflex lesion. All patients with single vessel disease and a positive test showed ischemic changes in the anterolateral leads. The location of the diseased vessel could not be predicted from the electrocardiographic site of ischemia (fig. 5). Of 45 men with multivessel disease, 28 (62%) had a positive test using a V5 lead, 40 (89%) using 11 leads (P < 0.01) and 43 (96%) using 14 leads (P < 0.01). The sensitivity of the exercise test in detecting multivessel disease was significantly better using 14 leads (96%) than an isolated CC6 (71%) or CM5 (76%) lead (P < 0.03). Of the two patients with multivessel disease and a negative exercise test using 14 leads, one had an 80% stenosis in the middle segment of the left anterior descending coronary artery and an occluded right coronary artery. The other patient had a 70% stenosis in the proximal left anterior descending and distal left circumflex arteries and an 80% stenosis in the right coronary artery.

Depth of ST Segment Depression

There were 19 men with ST-segment depression ≥3 mm in at least one of the 14 leads (table 2). A high grade stenosis (≥70%) of the left main coronary artery, proximal left anterior descending coronary artery or three vessel disease was seen in ten (53%) of these 19 patients. Of the nine

<table>
<thead>
<tr>
<th>Table 2. Depth of ST-Segment Depression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum depth of ST depression in any 1 of 14 leads</td>
</tr>
<tr>
<td>Number of patients with stenosis ≥70%</td>
</tr>
<tr>
<td>1. Three vessel disease (N = 27)</td>
</tr>
<tr>
<td>2. Left main stenosis (N = 3)</td>
</tr>
<tr>
<td>3. Proximal LAD stenosis (N = 23)</td>
</tr>
<tr>
<td>Number of patients with:</td>
</tr>
<tr>
<td>Any one of the above*</td>
</tr>
<tr>
<td>Lesion other than 1-3</td>
</tr>
<tr>
<td>No coronary stenosis ≥70%</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*One category only/patient.
Abbreviation: LAD = left anterior descending coronary artery.
remaining patients, six had stenosis $\geq 70\%$ in the mid or distal left anterior descending coronary artery, one had an $85\%$ proximal stenosis of a non-dominant left circumflex coronary artery and there were two patients with normal coronary arteries. The CM$_5$ lead alone registered ST-segment depression $\geq 3$ mm in 18 of the 19 cases.

ST-segment depression $\geq 3$ mm before Bruce stage II was always associated with multivessel disease. Of seven patients in this category, six had three vessel disease and the seventh patient had occluded right and distal left anterior descending coronary arteries. Only one of these seven patients was able to exceed $70\%$ of his maximal age predicted heart rate. In contrast, both patients with a false positive test $\geq 3$ mm performed Bruce stage III and reached $90\%$ of their maximal age predicted heart rate. The ECG remained positive for 5 min or longer in 12 of the 19 men who had ST-segment depression $\geq 3$ mm. Both patients with false positive tests were among these 12 men.

The depth of ST-segment depression which occurred in each lead was summed and an ST-segment "index" was established for the 64 patients who had positive test (fig. 6). In general, most ST-segment depression was seen in the six patients with a false positive test. The average sum of ST depression in this group ($13.2 \pm 3.1$) (mean $\pm 1$ SEM) was greater than the average observed for single vessel disease ($6.8 \pm 1.4$) ($P < 0.05$), but not significantly different than that observed for two ($11.2 \pm 2.2$) or three ($10.1 \pm 1.2$) vessel disease.

Exercise Capacity

There was a direct relationship between treadmill endurance time and the number of diseased vessels (fig. 7). Exercise capacity of patients without coronary disease was significantly greater than patients with single ($P < 0.01$) or two and three vessel disease ($P < 0.001$). Exercise capacity of patients with single vessel disease was also significantly better than the group with two to three vessel disease ($P < 0.01$). Stage III of the modified Bruce test provided a useful cut-off point since 30/31 (97%) of patients without coronary disease reached stage III whereas only 2/22 (9%) of patients with three vessel disease were able to reach this workload.

The time that a positive test developed during exercise was related to the number of diseased vessels (fig. 8). Patients with single vessel disease developed a positive test later than patients with two ($P < 0.05$) and three ($P < 0.001$) vessel disease. Of 13 patients with a positive test in at least one of the 14 leads before Bruce stage I, 12 (92%) had multivessel disease and the 13th patient had a proximal left anterior descending occlusion with normal left ventricular function. The pressure-rate product (heart rate $\times$ systolic blood pressure) was another useful parameter in determining the extent of coronary disease. The average pressure-rate
There was a direct relationship between workload and extent of coronary disease. Whereas 97% of "normals" entered Bruce stage III, only 1/5 and 1/10 patients with 2 and 3 vessel disease respectively performed this workload.

The average patient with single vessel disease had a positive test was 18,818 ± 837 for patients with three vessel disease vs 22,628 ± 1,161 (P < 0.02) with two vessel and 24,474 ± 2,288 (P < 0.01) with one vessel disease, respectively. Only 2/21 (10%) of patients with three vessel disease were able to generate a pressure-rate product greater than 25,000 at the time their test became positive.

The total duration of exercise in patients with a positive test was also related to the extent of coronary disease (fig. 9). The average patient with single vessel disease and a positive test can nearly finish Bruce stage II whereas the average patient with three vessel disease usually stops in the middle of Bruce stage I (P < 0.001). Of 21 patients with three vessel disease and a positive test, only one (5%) was able to enter Bruce stage III.

The amount of time a positive exercise test took to return to normal in itself was not related to the extent of disease (fig. 10). The electrocardiograms returned to normal in nine patients with three vessel disease in less than 1 min whereas ten patients were still positive 5 min after exercise. Of six
false positive tests, four patients still had a positive test 5 min after exercise. The results were more useful when exercise endurance time was studied in relation to the amount of time a positive test required to normalize. Of 23 men with ST-segment depression ≥1 mm persistent 5 min or longer following exercise, only six also performed Bruce stage III. Four of the six were false positives and one patient each had one and two vessel disease respectively. Among these 23 men, 12 were unable to complete Bruce stage I. All 12 had multivessel disease (three had two vessel and nine had three vessel disease).

Discussion

Several studies have shown that the sensitivity of a single lead exercise test can be increased by the addition of multiple leads. However, the number and location of leads required for optimal sensitivity and specificity have not yet been determined. Mason and Likar have shown that a modified 12 lead scalar ECG recorded during exercise was more sensitive than individual leads alone in detecting coronary disease but they did not evaluate commonly used bipolar lead systems (CM and CC). Other investigators have compared a CC and CM lead to V5 alone but they did not compare their results to angiographically documented coronary disease. Using a computer technique of ST-segment analysis have concluded that the most practical system of leads is the combination of a CM and CC lead recorded both during and postexercise. There are no data on the sensitivity and specificity of a modified 12 lead scalar ECG system in combination with CM and CC leads. The aim of this study was to evaluate the diagnostic value of each of the above lead systems in detecting coronary artery disease and in particular multivessel disease. Basic physiologic data collected during exercise were also studied to determine its usefulness in predicting multivessel disease using a multiple lead ECG system. The population studied is relatively homogeneous in that all subjects were men, not enrolled in an exercise training program. All had a normal resting electrocardiogram and no previous history of myocardial infarction.

Sensitivity of Single vs Multiple Leads

The sensitivity of the ECG test result was significantly greater using multiple leads compared to a single lead system. Although the sensitivity of a CC and CM lead were approximately equal (65–68%), the combination of both leads together increased the sensitivity to 77%. The V5 lead alone detected only 56% of patients with coronary disease, significantly less than the 76% observed for the 11 lead ECG (P < 0.05), the 79% observed for the combination of CM, CC and CL (P < 0.05) and the 88% sensitivity when all 14 leads were combined (P < 0.01). The recording of modified limb leads did not result in increased sensitivity.

The predictive value of a positive test for coronary disease did not decrease with the addition of multiple leads. In general, myocardial ischemia produces ST-segment depression in the anterolateral leads and the magnitude of ST segment depression is related to R wave voltage. For these reasons, single lead systems such as CM or CC lead which augment the height of the R wave have become popular in evaluating patients with coronary disease. It is clear from our results that a combination of leads such as CM, CC, and CL is preferable to using either a CM or CC lead alone. Although the CL lead (inferior) was positive in only one patient without changes in other leads, we feel it is worth recording since it is the only lead of the three which reflects primarily inferior wall changes. The usefulness of the CL lead in evaluating coronary disease in a population other than that evaluated in this study remains to be determined.

False negative exercise tests were more common in patients with single vessel disease. Although all six men with isolated left anterior descending coronary disease had a positive test, 3/10 patients with isolated right coronary disease had a positive test, and 3/5 with left circumflex disease had a negative test despite the use of a 14-lead system. Other investigators have also reported an increased incidence of false negative tests with isolated left circumflex or right coronary artery disease. In general, the location of single vessel disease could not be predicted on the basis of which leads became positive, a finding observed by others. Multivessel disease more frequently produced a positive test than single vessel disease regardless of the number of leads used. However, the sensitivity of the V5 and CM leads in detecting multivessel disease was only 62% and 76% respectively compared to 96% (P < 0.01) using a 14 lead system.

The Slow Upsloping ST Segment

The inclusion of a slow upsloping ST-segment depressed ≥2 mm, 0.08 sec after the J point substantially increased the sensitivity of the test in nearly all lead systems without decreasing the specificity. When 14 leads were used, the upsloping criterion for positivity did not change the sensitivity since there was always one lead which showed horizontal ST segment depression ≥1 mm. This would explain the high incidence of coronary disease observed with this type of ECG response. The ischemic vector clearly can produce a slow upsloping change in some leads and horizontal ischemic changes in other leads as illustrated in figure 3. Goldschlager and co-workers have found that a slow upsloping pattern depressed ≥1.5 mm, 0.08 sec after the J point in a CM lead, was associated with coronary disease in only 32% of patients. Stuart and Ellestad have found that a slow upsloping ST segment depressed ≥2 mm, 0.08 sec after the J point in a CM lead, was associated with coronary disease in 52–89% of patients. Our results suggest that in a symptomatic population a slow upsloping ST segment depressed ≥2 mm, 0.08 sec after the J point should be considered as a positive exercise test whenever a CM, CC, or a modified 11 lead ECG system is being used.

Depth of ST-Segment Depression

Several investigators have reported an increased incidence of proximal left anterior descending, left main, and three vessel disease among patients in whom the ST segment becomes depressed ≥2–3 mm in the CM lead during a treadmill test. In our series of 19 men with ST-segment depression ≥3 mm, only ten (53%) had one of the above “high risk” lesions. Furthermore, most of our patients with proximal left anterior descending and three vessel disease did not have ST segment depression ≥3 mm despite the use of a 14 lead ECG system.
The extent of coronary disease roughly correlated with the total amount of ST-segment depression in the 14 leads. However, the degree of overlap between false positive tests and patients with one, two, and three vessel disease made it impossible to accurately predict the extent of coronary disease from the sum of ST-segment depression alone. The duration of a positive test postexercise in itself was not helpful in determining the extent of coronary disease regardless of the lead system used. This finding has been reported by other investigators. Although depth of ST-segment depression and persistence of positivity following exercise did not discriminate all “high-risk” patients, the addition of exercise endurance time as an associated variable greatly increased the usefulness of these parameters. Inability to complete Bruce stage I associated with ST-segment depression ≥3 mm and/or a test which remained positive 5 min or longer following exercise was always associated with multivessel disease, usually three vessel disease.

Exercise Capacity and Detection of Multivessel Disease

The patient population in this study was relatively homogeneous since all patients were men with a normal resting electrocardiogram. No patient had a previous history of myocardial infarction and 74% had a normal left ventricular contraction pattern at rest. In this homogeneous group, we found a significant difference in treadmill endurance time and the number of diseased vessels. Only 10% of patients with three vessel disease and 21% of patients with two vessel disease were able to complete Bruce stage II whereas 97% of patients without significant disease completed this workload (P < 0.001). The onset of an ischemic ECG response during the 3 min warm-up phase prior to entering Bruce stage I was associated with multivessel disease 92% of the time. The pressure-rate product at initial ischemia was another useful parameter in separating single from multivessel disease. Only 10% of patients with three vessel disease and 23% of patients with two vessel disease were able to generate a pressure-rate product more than 25,000 when their ECG became positive. Finally, the total amount of exercise performed with a positive test was helpful in separating single from multivessel disease. Whereas 80% of patients with a false positive test were able to finish Bruce stage II, only 23% and 5% of patients with a positive test and two and three vessel disease respectively were able to perform this workload (P < 0.01).

Ellestad and Wan and Goldschlager et al. have also reported more coronary events and more extensive coronary disease when a positive exercise test occurs at a low workload.

Conclusions

In conclusion, the diagnostic value of exercise testing in a symptomatic population is significantly enhanced using multiple leads compared to a single lead system. Fewer patients with multivessel disease are missed if more electrodes are used. Because 14 lead recordings are slightly more time consuming, we recommend a combination of CM₅, CC₅, CL (inferior) and V₅ leads as an acceptable alternative, should time be a limiting factor in a busy clinical laboratory. If the V₅ lead is not recorded, the positive electrode for the CC and CM leads should be placed where the optimal Rs type QRS configuration in CM₅ and CC₅ is observed.

The exercise test was most useful when 14 leads were used and other parameters were evaluated such as 1) the time ischemia first appeared, 2) the pressure-rate product at the time that ischemia first appeared, and 3) the maximum exercise capacity that could be attained. These physiological responses to exercise were valuable parameters when used in conjunction with the multiple lead ECG since they greatly improved the predictive value of the test in finding multivessel disease.

Acknowledgment

The authors wish to thank Margot Méthée, R.N., and Doris Morissette, R.N., for their technical assistance; to Diane Roy for secretarial assistance; and to Jean Gauthier for his excellent contribution in preparing the illustrations.

References

21. McHenry PL, Philippus F, Knoebel S: Correlation of computer-
TREADMILL TESTS OF HEALTHY WOMEN/Sheffield et al.

79

Maximal Heart Rate and Treadmill Performance of Healthy Women in Relation to Age

L. Thomas Sheffield, M.D., John A. Maloof, M.D., James A. Sawyer, M.D., and David Roitman, M.D.

SUMMARY Maximal treadmill exercise heart rate, work capacity and electrocardiographic response were studied in 95 asymptomatic, predominantly sedentary women between the ages of 19 and 69 years. Average maximal heart rate (MHR) was found inversely related to age, such that MHR = 216 - 0.88 (years of age) ± 10 beats/min (X±1 SD).

Treadmill exercise endurance was 7.64 min ± 1.99. The reduction of treadmill endurance with advancing age was not statistically significant.

IN ORDER PROPERLY TO EVALUATE the results of maximal or near maximal treadmill tests for coronary artery disease or for the quantification of cardiovascular reserve in valvular heart disease or cardiomyopathies, normal response values are required for comparison. These reference values should include the maximal treadmill work capacities of normals, the heart rates attained in performing maximal exercise and the electrocardiographic responses of normals to such testing.

Maximal exercise heart rate and work capacity throughout childhood and adulthood in women and men are sparsely documented.1-4 Published studies on women have tended to concentrate on fairly narrow age ranges as in studies of college students,6-8 studies limited to individuals actively engaged in physical education programs, or studies limited to asymptomatic patients who should not be classified as normal.7-9 One of the largest groups of women was studied by Cumming and colleagues, 357 women between the ages of 20 and 83 years.10 However these authors did not state what evidence they employed to confirm that their subjects were normal, nor was it reported whether the volunteers were taking any medications at the time of testing. Only if the range and variability of maximum exercise heart rate in women is known is it possible to apply the graded exercise test principle appropriately to women, i.e., to know with reasonable confidence what level of tachycardia represents 90% of average maximum exercise heart rate for a given age, in order to recognize when in the course of an exercise test a near maximal intensity of exercise is taking place.4 Additionally, it would be desirable to establish normal ranges of treadmill exercise endurance with respect to the age of normal women volunteers.

Asymptomatic ST-segment depression occurred in 6% of subjects. In 5% the ST segment slopped upward, and in 1% it was flat. Mean age of women with ST depression was 52 years, compared with 39 years mean age of all subjects. Premature beats during exercise were found in 20 of 95 subjects, and were not related to age.

Graded exercise testing of women employing target heart rates should use heart rate tables developed especially for women. These tables do not require correction for athletically trained or sedentary life-style.

Subjects and Methods

The volunteers studied were 95 asymptomatic women between the ages of 19 and 69 years. Their mean age was 38.9 years, and there was quite even distribution of their ages as shown in figure 1. Their mean height was 164.8 cm ± 5.8 (in this and subsequent values, the number preceding the ± symbol represents the mean; the number following it, one standard deviation of the mean). Mean
Improved efficiency of treadmill exercise testing using a multiple lead ECG system and basic hemodynamic exercise response.
B R Chaitman, M G Bourassa, P Wagniart, F Corbara and R J Ferguson

Circulation. 1978;57:71-79
doi: 10.1161/01.CIR.57.1.71
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1978 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/57/1/71

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/