Submaximal Exercise Testing in a Random Sample of an Elderly Population

By C. P. Riley, M.D., A. Oberman, M.D., T. D. Lampton, M.D., and D. C. Hurst, Ph.D.

SUMMARY
To examine the electrocardiographic response to exercise in an older population, 280 participants in a longitudinal study of cerebrovascular disease were tested. Subjects were randomly selected from the total 50 to 69-year-old population of Birmingham, Alabama. Approximately 60% of the participants reached a heart rate more than 80% of their predicted maximal heart rate.

Subjects were divided into three groups on clinical grounds: (I) vascular disease, (II) risk factor(s) only, and (III) normal. Positive tests (at least 0.10 mv of ischemic ST-segment depression) were most frequent in group I (24%), though not significantly different from group II (19%) and group III (12%).

Hypercholesterolemia was significantly associated with a positive exercise test only in those subjects with vascular disease. Nonspecific ST-T wave changes on the resting electrocardiogram were associated with a positive test in all subjects, but with only a borderline test in those subjects without vascular disease. No significant associations were noted between abnormal exercise test and either cigarette smoking or hypertension.

Additional Indexing Words:
Blood pressure  Cigarette smoking  Cholesterol  Coronary disease
Coronary risk factors  Epidemiology  Electrocardiography
Vascular disease

Exercise testing contributes to the functional evaluation of patients with cardiovascular diseases and facilitates the diagnosis and management of patients with ischemic heart disease. Information on exercise testing is largely limited to groups of selected subjects, primarily male volunteers or patients, and often to groups less than 50 years old. Longitudinal studies of these groups indicate that an abnormal electrocardiographic response to exercise infers an increased risk of symptomatic coronary heart disease. The prognostic and diagnostic meaning of a positive exercise test in an older population, especially in those individuals who are otherwise clinically normal, is not known.

Controversy exists about virtually every facet of exercise testing—the type of test employed, criteria for a positive test, lead selection, and types of recording devices. Most investigators would agree, however, that the testing procedure and the interpretation of results must be tailored to the population being studied and the information being sought. The purpose of this study is to examine the electrocardiographic response to exercise of an elderly population and to show that the testing procedure employed is both safe and feasible.
Subjects selected for exercise testing are participating in the Birmingham Stroke Epidemiology Study, a prospective investigation designed to identify the stroke-prone individual.\textsuperscript{20, 21} Initially, the city of Birmingham, Alabama (population 340,000), was divided into seven subpopulations using the 1960 census tract data. Each subpopulation contained from six to 11 census tracts, grouped by median age, race, median schooling, median income, labor force (working and unemployed, male and female), and population per household. Individual blocks were randomly selected from a census tract, and everyone between the ages of 50 and 69 in these blocks was interviewed. In the city of Birmingham there were approximately 61,000 persons in this age group. Eight thousand of these subjects from selected blocks receive a lay-administered health questionnaire; 2,000 were done each year. The questionnaire is designed specifically to elicit neurologic and cardiovascular symptoms, as well as provide an evaluation of general health. Of the 8,000 persons being interviewed, a randomly selected sample of 3,000 receive a medical examination and laboratory testing at a rate of 750 evaluations per year. Each year of interviews and examinations constitutes a complete subsample of the population.

**Methods**

Of the last 544 subjects examined, 280 persons (51.5\%) underwent submaximal exercise testing. Table 1 shows the race, sex, and age distribution of tested subjects. One hundred fifty-six subjects (28.7\%) were excluded for one or more medical reasons. Physical deformity, acute illness, ST-segment depression in lead V\textsubscript{5}, and dyspnea comprised the majority of medical exclusions. One hundred eight subjects (19.9\%), although potentially testable, were not tested because of unavailability of testing personnel or mechanical difficulties; only three of these eligible subjects refused to undergo the test.

Subjects report for examination in the fasting state. Initial laboratory testing includes cholesterol, triglycerides, uric acid, protein-bound iodine, VDRL (veneral disease research laboratory tests), glucose 2 hours after an oral load of 75 g of carbohydrate, urinalysis, vital capacity, supraorbital thermography, resting electrocardiogram, and roentgenograms of the chest.

Submaximal exercise testing of subjects for whom testing was considered safe or possible was begun during the year 1967-68. Subjects selected for this report were drawn from portions of two sample years and do not constitute a complete subsample of this population. A disproportionately large number of subjects from higher income strata are included. This preliminary report describes the exercise response of 280 (51.5\%) of the last 544 subjects examined.

Exercise testing was done on a motor-driven treadmill by the method of Sheffield and associates.\textsuperscript{6} All subjects had their oral carbohydrate load for blood glucose testing 1 hour before resting and exercise electrocardiograms. Time and personnel commitments required that an oral glucose solution for subsequent (2-hour) blood glucose testing be administered before resting and exercise electrocardiograms were made. Smoking was not permitted for the hour preceding the electrocardiogram. Subjects were excluded from testing if there was any suspicion of myocardial infarction during the last year, moderately severe dyspnea (inability to walk one level block or climb one flight of stairs), pertinent physical deformities or acute illness, or electrocardiographic abnormalities of left bundle-branch block, second or third degree heart block, or ST-segment depression in lead V\textsubscript{5} (Minnesota code items 41, 42). All subjects taking digitalis preparations were also excluded. Subjects with nonspecific ST-segment or isolated T-wave changes (Minnesota code items 43, 44, 51-53) were included in this study.

Leads from an ECG cable were attached over the clavicles at the midclavicular line and anterior superior iliac spines and at V\textsubscript{5} after vigorous skin abrasion with acetone and a small abrasive wheel. Recordings of V\textsubscript{5} were obtained continuously as an analog signal on magnetic tape on a data acquisition cart as described by Caceres and associates.\textsuperscript{22, 23}

The signal was simultaneously viewed on an oscilloscope and recorded on paper for the last 6 of every 30 seconds during exercise and for 5 minutes after exercise. An attempt was made to

<table>
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<tr>
<th>Table 1</th>
<th>Race, Sex, and Age Distribution of Exercised Subjects</th>
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<td>Race</td>
<td>Sex</td>
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exercise each subject to 90% of his mean predicted, maximal heart rate, as determined by Lester and associates.\textsuperscript{24, 25} Exercise was begun at 1.7 mph and a 10% grade without any preceding warmup period. The subject's target heart rate was attained as quickly as possible by gradually increasing both treadmill grade and speed and was maintained for at least 2 minutes. The total duration of exercise was approximately 5 minutes for most subjects.

The test was terminated with the appearance of a positive ST-segment response, rhythm or conduction disturbance, chest pain, weakness, undue fatigue, or dyspnea, or after 5 minutes of exercise regardless of pulse rate attained. A test was classified positive if ST-segment depression of 0.10 mv or greater occurred, beginning with J-point depression and continuing flat or downsloping for a duration at least equivalent to the QRS duration before returning to the isoelectric line, arbitrarily defined as the F-R (FQ) junction. Similar ST-segment depression of 0.05 to 0.09 mv was considered borderline. Tests showing frequent premature ventricular contractions or a tachyarrhythmia during or after exercise, without positive or borderline ST-segment depression, were placed in a separate category. No distinction was made between exercise and postexercise criteria or electrocardiographic abnormality. ST-segment depression was not adjusted for R-wave voltage.

Using predetermined criteria, the same observer (C.P.R.) measured and graded all recordings. To establish the validity of the electrocardiographic readings, Dr. L. T. Sheffield, University Hospital Heart Station, was asked to classify 30 randomly selected exercise electrocardiograms as negative, borderline, or positive. Both observers agreed perfectly on 24 tracings, differed slightly on five tracings, and more on one tracing. Of the six disagreements C.P.R. over-read two and under-read four electrocardiograms in comparison with L.T.S. As a check on reliability the observer randomly selected and re-read 10% of the recordings. Variation between the two readings was small and random resulting in no change of classification of any of the electrocardiograms.

Subjects tested were separated into three groups: group I, subjects having clinical evidence of coronary disease, peripheral vascular disease, cerebrovascular disease, or electrocardiographic evidence of myocardial infarction; group II, subjects not in group I possessing one or more of the following risk factors: (a) elevated blood pressure (at least 160 mm Hg systolic or 95 mm Hg diastolic, or both), (b) hypercholesterolemia (serum cholesterol above 280 mg%), (c) current cigarette smoking in any amount, (d) ST-T wave abnormalities not meeting exclusion criteria, on the resting electrocardiogram (Minnesota code items 43, 44, 51-53)\textsuperscript{26}; group III, subjects considered “normal” (that is, not in group I or II).

**Results**

One hundred eighty-nine subjects (67.5%) had a negative test; 31 (11.1%) were borderline, and 53 (18.9%) were positive (table 2). Seven subjects (2.5%) had a rhythm disturbance during exercise or within the first 2 minutes after exercise. All the rhythm disturbances were of short duration and terminated spontaneously. No subject developed a myocardial infarction or sudden death shortly after testing. No subject had symptomatic postural hypotension, syncope, or prolonged chest pain.

Figure 1 shows the relative sizes of two age groups, 50 to 59 years old and 60 to 69 years old, in each of the clinical groups. A larger proportion of clinically normal subjects (group III) was found in the younger age group, and a larger proportion of subjects with vascular disease (group I) was in the older age group. In each of the clinical groups

| Table 2 |
|---|---|---|---|---|
| **Distribution of Electrocardiographic Responses to Exercise by Clinical Groups** |
| Clinical groups | Exercise ECG response |
| | Negative | Borderline | Positive |
| | No. | % | No. | % | No. | % |
| I. Vascular disease | 28 | 59.6 | 6 | 12.8 | 12 | 24.5 | 1 | 2.2 | 47 |
| II. Risk factor | 122 | 66.7 | 22 | 12.0 | 35 | 19.1 | 4 | 2.2 | 183 |
| III. "Normal" | 39 | 78.0 | 3 | 6.0 | 6 | 12.0 | 2 | 4.0 | 50 |
| Total | 189 | 67.5 | 31 | 11.1 | 53 | 18.9 | 7 | 2.5 | 280 |
Electrocardiographic exercise response in clinical groups by age.

the relative percentage of positive tests increased with age. Also more whites than blacks and more men than women had positive tests (fig. 2). These differences, primarily in the 60 to 69-year-old age groups, were not large enough to be significant at the 0.05 level. Further age-sex-race breakdowns are indeterminable because of sample size.

Exercise electrocardiographic response varied in the three clinical groups (table 2). Of

the subjects tested 24.5% of those with vascular disease, 19.1% of those in the risk factor group, and 12.0% of the normals had positive tests. If table 2 is set up as a contingency table and a chi-square value computed, no statistically significant differences exist among the three groups. The distribution patterns of the three groups are very similar.

Figure 3 shows the time of occurrence of exercise electrocardiographic abnormalities. Bars to the left of the vertical line indicate the percentage of subjects displaying a particular abnormality who manifested this change only during exercise or within the first 30 seconds after exercise. These abnormalities would have been missed without continuous monitoring of the ECG signal. Bars to the right of the vertical line indicate the percentage of subjects with abnormalities occurring in the postexercise period. Two subjects who had positive tests after exercise also had transiently positive tests during exercise. Figure 3 also indicates the importance of continuous monitoring for the detection of serious rhythm disturbances.

Figure 4 shows the cumulative percentage of subjects attaining 50 to 90% of their predicted maximal heart rates. The groups having borderline and negative test responses did not differ appreciably in percentage of predicted maximal heart rates attained. Sixty per cent of subjects with borderline and negative tests achieved at least 80% of their
predicted maximal heart rate; these subjects exercised sufficiently to produce a heart rate ranging from 147 beats/min at age 50 to 140 beats/min at age 69. Fifty-eight per cent of subjects with positive tests achieved similar heart rates. Approximately 10% of subjects with negative tests sustained heart rates of 160 beats/min or more without ill effects. The number of risk factors present was related to the prevalence of vascular disease in both the tested and untested groups. While more vascular disease exists in the untested group, the patterns displayed are similar, an increasing risk of vascular disease with an increasing number of risk factors (fig. 5). The distribution of risk factors in the tested subjects was examined in detail to determine whether a similar relationship existed between the number of risk factors and the appearance of a positive exercise test. Such a trend was suggested but was only just significant at the 0.05 level.

The relative risk is the ratio of the prevalence of a positive or borderline exercise ECG among those subjects with the risk factor to the prevalence of the same exercise ECG abnormality in those subjects without the risk factor. Table 3 shows the relative risk of different exercise electrocardiographic responses conferred by each of the four risk factors measured. An elevated cholesterol was associated with more positive tests in the vascular disease group \( P < 0.01 \). All of the various combinations of risk factors were examined in detail to see whether any particular combination was more important. No such relationship was apparent with the number of cases available.

### Table 3

<table>
<thead>
<tr>
<th>Clinical group*</th>
<th>Risk factor</th>
<th>Positive exercise test</th>
<th>Borderline exercise test</th>
</tr>
</thead>
<tbody>
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<td>Vascular disease</td>
<td>Smoker</td>
<td>1.484</td>
<td>1.23</td>
</tr>
<tr>
<td>Vascular disease</td>
<td>Chol. ≥ 280</td>
<td>2.000</td>
<td>9.23</td>
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<tr>
<td>Vascular disease</td>
<td>BP ≥ 160/95</td>
<td>1.667</td>
<td>1.11</td>
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<tr>
<td>Vascular disease</td>
<td>ST-TΔ</td>
<td>2.800</td>
<td>4.35</td>
</tr>
<tr>
<td>No vascular disease</td>
<td>Smoker</td>
<td>1.065</td>
<td>0.11</td>
</tr>
<tr>
<td>No vascular disease</td>
<td>Chol. ≥ 280</td>
<td>1.237</td>
<td>1.52</td>
</tr>
<tr>
<td>No vascular disease</td>
<td>BP ≥ 160/95</td>
<td>0.682</td>
<td>0.58</td>
</tr>
<tr>
<td>No vascular disease</td>
<td>ST-TΔ</td>
<td>2.804</td>
<td>7.69</td>
</tr>
</tbody>
</table>

*Vascular disease = clinical group I; no vascular disease = clinical groups II and III.
Because glucose loading by necessity preceded electrocardiography in the testing routine, the effects of this glucose ingestion on resting and exercise electrocardiograms in this population were determined in an independent and separate study to be reported in detail later.\textsuperscript{28} Essentially, 35 subjects with borderline or positive exercise electrocardiograms were retested on two separate days being randomly assigned to either a glucose or placebo solution 1 hour before the exercise. Using the same method described in the present study, prior glucose ingestion by subjects resulted in the following changes in the resting electrocardiogram: significant reduction in T-wave amplitude, an increase in R-wave amplitude, an increase in heart rate and further ST-segment depression of any already present. Although maximal heart rates attained during exercise after either glucose or placebo were equivalent, positive and borderline tests occurred more frequently after glucose. Exercise electrocardiographic classifications were significantly more abnormal after glucose ($P < 0.01$). Computer measurements of the S-T integral after exercise showed less variability, but classifications based on computer analysis\textsuperscript{30} are not yet complete.

Discussion

Submaximal treadmill exercise testing of an elderly population has been shown by this study to be both safe and feasible. The lack of complications may be attributed in part to constant electrocardiographic monitoring with immediate cessation of exercise after the appearance of rhythm disturbances or a positive test. Termination of a test immediately with the onset of chest pain, undue fatigue, or severe dyspnea, or when the patient complains of dizziness or appears hypotensive also adds a large margin of safety. Up to 70\% of the examined population is considered potentially testable. Most subjects excluded had physical deformities, acute illness, dyspnea of at least moderate severity, or ST-segment depression in lead V$_5$ of the resting electrocardiogram. A large number of subjects were not tested at the beginning of this study because of initial mechanical difficulties or unavailability of testing personnel. Our current rate of testing is approximately 60\% of the total group examined, or 86\% of those eligible for testing. Although many subjects failed to attain the target (predicted) heart rates, the amount of exercise they performed was probably near-maximal for them because of cardiovascular, pulmonary, and musculoskeletal limitation in this age group. Few subjects had performed treadmill exercise before; however, less than 1\% of potentially testable subjects refused the test.

Any test used in a prospective study of a large population should be safe and feasible and should provide a maximum of sensitivity and specificity. Although the feasibility and specificity of the standard Master's double two-step test have been repeatedly demonstrated, the test lacks the sensitivity of submaximal and maximal exercise testing. Studies by Sheffield and associates\textsuperscript{8} provide interesting data comparing the yield of positive responses in subjects with ischemic heart disease with graded submaximal exercise (GXT) and the two-step exercise test. Overall, the GXT evoked a positive response in an additional 24\% of patients. An additional small percentage of positive responses can be obtained by pushing the patient to maximal levels; however, safety, feasibility, and perhaps specificity suffer with maximal exercise testing.

Estimation of the prevalence of ischemic heart disease in a population is difficult because of the large number of subjects with clinically latent coronary disease.\textsuperscript{30} Longitudinal studies of subjects with an abnormal exercise electrocardiogram have confirmed that these subjects have an increased risk of coronary heart disease morbidity and mortality. Robb and Marks\textsuperscript{17} found even mild "ischemic" ST-segment depression (0.01 to 0.09 mv) to be associated with a coronary heart disease mortality ratio of 2.5. In a group of 81 manual workers 50 to 64 years old studied by Astrand\textsuperscript{81} 19\% subjected to "maximal" exercise testing had ischemic ST-segment depression (0.05 mv or more). These subjects
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attained a mean maximal heart rate of 157 beats/min. Berkson and associates demonstrated ischemic ST-segment depression (0.05 mv or more) in 20% of 49 men 40 to 59 years of age. These subjects attained heart rates of 131 to 170 beats/min. In the study of Blackburn and co-workers, less than 1% of railwaymen (four of 570) between the ages of 45 and 64 years had ischemic type ST-segment depression after a 3-minute treadmill walk at 3 mph on a 5% grade. Thirty per cent of our 280 subjects showed ST-segment depression of 0.05 mv or more. Nineteen per cent demonstrated ST depression of 0.10 mv or more. Assuming no reader discrepancies, two explanations for the differences between these studies seem plausible, other than characteristics of the populations themselves; (1) the differences are due to a higher prevalence of latent ischemic heart disease in the population we studied; (2) prior glucose ingestion by our subjects accentuated their ST-segment response to exercise. The percentage of subjects showing 0.10 mv or more ST depression in this study was essentially the same as the percentage showing 0.05 mv or more ST depression in the studies by Astrand and Berkson. Glucose ingestion has been shown to accentuate ST depression, and at least some of the increased prevalence of positive tests in this study might be explained on this basis. The percentages of positive tests in these three studies using different criteria are remarkably similar (19%, 19%, and 20%). The low prevalence of abnormal exercise tests in the study by Blackburn and associates may be due to the relatively low level of exercise performed.

Several longitudinal studies have identified the following as coronary risk factors: cigarette smoking, elevated blood pressure, hypercholesterolemia, and nonspecific ST-T wave changes on the resting electrocardiogram. As expected, the more risk factors our subjects had, the more prevalent vascular diseases were. In some subjects minor ECG changes may be the only manifestation of latent coronary heart disease; however, the nonspecific and labile nature of these changes is well recognized. We prefer to consider such electrocardiographic changes as a risk factor rather than evidence of the presence of coronary heart disease.

Subjects without vascular disease in this study but with ST-T wave changes on the resting electrocardiogram had a significantly (P < 0.001) increased risk of a borderline exercise test (0.05 to 0.09 mv). Both (the vascular disease and the no vascular disease) groups of subjects had an increased risk of a positive exercise test in the presence of ST-T wave changes on the resting ECG. Although the relative risks of a positive test in the two groups were equal (2.80), the relative risk in the larger clinically normal group was more significant. Such a response may have different implications in the normal group from those in the group with vascular disease. ST-T wave changes are known to occur after ingestion of a glucose solution. The electrocardiographic findings observed in subjects in this study were definitely influenced by prior glucose ingestion. Perhaps the borderline and positive responses observed in normal subjects were affected differently by glucose than in subjects with vascular disease. Whether specificity of the exercise test was reduced or sensitivity increased (or both or neither) may be answered in the prospective portion of our study.

An elevated serum cholesterol conferred a significantly (P < 0.01) increased risk of a positive exercise test in subjects with vascular diseases but not in the remainder of subjects tested. Berkson and co-workers and Bellet and associates found an increased risk of an abnormal exercise test in subjects with an elevated cholesterol, but Keys' group did not. Although findings in these studies are not too dissimilar from ours, our results may have other implications. Hypercholesterolemia increased the risk of a positive test (0.10 mv or more), but not a borderline test (less than 0.10 mv), in those subjects who already had clinically recognizable atherosclerosis. Assuming that a positive exercise test implies a similar risk of coronary heart disease mortality in both groups, an elevated cholesterol in
subjects over 50 years old may or may not have significance. In those subjects who have somehow tolerated an elevated cholesterol past the age of 50 without developing overt atherosclerosis, an elevated cholesterol does not confer an increased risk of coronary heart disease mortality.\textsuperscript{43, 44} Obviously, this is only speculation, and prospective evaluation of these subjects is necessary to clarify this relationship.

Cigarette smoking in any amount did not present a significantly increased relative risk of a positive or a borderline exercise test. In the study reported by Keys and associates,\textsuperscript{42} a reversed trend was seen in smokers (that is, fewer abnormal exercise tests among heavy smokers than among other smokers or nonsmokers). Heavy smokers, however, have been shown to have a poorer exercise performance and a higher mean arterial pressure during exercise.\textsuperscript{45, 46} Because of elevated systolic pressure and suspected alterations in myocardial metabolism, myocardial oxygen consumption per beat in heavy smokers is probably higher. The stress to the coronary circulation is correspondingly greater than in nonsmokers. In this age group many heavy smokers have pulmonary dysfunction which limits their exercise performance. Attaining relatively high heart rates (above 80\% of predicted maximal heart rate) is difficult. Determination of the exact relationship of cigarette smoking to the exercise electrocardiographic response in this age group will be difficult.

Subjects with elevated blood pressure did not have more positive or borderline tests. Although this finding appears different from that of Bellet and Roman,\textsuperscript{47} several differences in these studies should be examined. Bellet and Roman studied only hypertensive subjects. No attempt was made by them to exclude those subjects who already had ischemic ST-segment depression in lead V\textsubscript{5} of a resting electrocardiogram. We have excluded these subjects from exercise testing because they already have evidence of ischemic heart disease (that is, subendocardial ischemia as manifested by ST-segment depression in lead V\textsubscript{5}). These subjects usually show further ST-segment depression during exercise, but this does not necessarily indicate coronary heart disease. None of the subjects we tested had systolic blood pressure of 200 or more or diastolic blood pressure of 120 or more. Most of the hypertensive subjects we tested had blood pressures ranging from 165 to 180 systolic and 95 to 100 diastolic. Analyses of larger numbers of our subjects tested in the future will permit evaluation of the exercise electrocardiographic response versus different levels of blood pressure. Keys and associates,\textsuperscript{42} showed a positive association of abnormal exercise tests with extreme obesity and the highest levels of blood pressure only.

The increased prevalence of abnormal exercise electrocardiograms with increasing age confirms an earlier report.\textsuperscript{31} This finding is consonant with existing knowledge of the course of atherogenesis with advancing age. The apparent lack of race or sex differences in the distribution of exercise electrocardiographic responses is of interest, but numbers are too small to draw conclusions.

The finding of ST-segment changes during exercise in such a large proportion of clinically normal subjects raises many questions about the pathophysiology involved. Exercise testing may indicate a pathophysiologic response but does not reveal the underlying mechanism. The abnormal ST-segment response during exercise may be due to anxiety,\textsuperscript{48} hyperventilation,\textsuperscript{49} or vasoregulatory asthenia,\textsuperscript{50} rather than overt or latent coronary heart disease.

Near-maximal exercise in older, physically unfit individuals may push the oxygen needs of the heart to a point where even structurally normal vessels may be unable to meet the demands. This relative ischemia may lead to alterations in myocardial metabolism resulting in ST-segment changes. An alternative hypothesis is derived from the knowledge that even younger individuals have at least slight to moderate structural coronary disease.\textsuperscript{51, 52} In the clinically normal group coronary flow suffices for limited activity due to collateral flow. During the stress of moderately severe exercise collateral flow becomes insufficient.
and myocardial ischemia results. Both morphologic and physiologic factors probably play a role in the genesis of an abnormal exercise test in this population.

Information from the prospective portion of this study will resolve the question of whether a positive ST-segment response infers a similar risk of death from coronary heart disease in this older population as Robb and Marks\textsuperscript{17} have shown in middle-aged males.

References


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