Comparative Effects of Aging and Coronary Heart Disease on Submaximal and Maximal Exercise

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SUMMARY
The relative contributions of aging and coronary heart disease to the impairment of functional capacity were assessed in 117 coronary patients, 117 age-matched healthy middle-aged men, and 62 healthy young men by utilizing a multistage treadmill test of maximal exercise.

With aging alone, duration of exertion and maximal exercise heart rate were diminished while maximal systolic pressure increased. The percentage of heart rate reserve from submaximal (stage 1) to maximal exercise was unaltered so that the relative heart rate stress of submaximal work on the heart was not affected. Transient postexertional S-T depression was related to increasing age and high cardiac work loads.

With coronary disease, maximal duration, maximal heart rate, maximal systolic pressure, and heart rate difference (maximal heart rate during exercise minus resting heart rate just before exercise) were all reduced, while the relative heart rate stress of submaximal exercise was greater.

The frequency of S-T depression was both age and disease dependent. Postexertional S-T depression of myocardial ischemia was prolonged and usually associated with angina in patients with coronary occlusive disease and subnormal performance in contrast to a more transient painless response which occurred in healthy subjects with performance which was “supernormal” in comparison with normals who exhibited no S-T depression.

Additional Indexing Words:
Myocardial ischemia S-T segment depression Maximal exercise performance
Relative exercise performance Heart rate Blood pressure Angina

CORONARY heart disease exhibits marked variability in its clinical manifestations. While some patients are disabled by angina pectoris, others surviving myocardial infarction pursue their usual activities with little or no symptoms. Nevertheless, hemodynamic studies indicate that most coronary patients have evidence of impaired myocardial contractility.1–6 When stressed by exercise or isoproterenol infusion, they show subnormal increments in cardiac output, stroke volume, and systolic ejection rate.3, 4, 6 More advanced disease may manifest overt left ventricular failure with elevated resting left ventricular end-diastolic and pulmonary capillary pressures.1, 2, 5

In a parallel manner, advancing age also adversely affects cardiovascular function. Whereas older individuals show only slight abnormalities at submaximal work loads, their maximal exercise performance is significantly limited.6–14 Oxygen consumption, heart rate, stroke volume, and cardiac output are all reduced at high work loads. Consequently, most middle-aged coronary patients suffer from the added limitations of both disease and increasing age.

Many clinicians limit exercise testing of coronary patients to simply detecting myo-
cardiac ischemia from postexertional S-T depression. Yet with slightly more effort, an objective assessment of each patient's functional capacity* can be obtained. In this regard, maximal exercise on a multistage treadmill has proved to be a useful test. In less than 12 min, asymptomatic as well as a class IV cardiac patients (New York Heart Association classification) can be exercised using the same test procedure, and their performance compared quantitatively to that of normal subjects.

This study was undertaken to define the maximal exercise capacity of normal men and coronary patients and assess the relative contributions of aging and disease to the overall functional limitations of an individual patient. In addition, the prevalence and multifactorial nature of postexertional S-T depression was examined in both groups and a broader concept of electrocardiographic ischemia proposed.

*Physiologically, functional capacity is maximal oxygen intake, or aerobic power, which defines the product of maximal cardiac output and maximal arterial-mixed venous difference, or maximal circulatory transport of oxygen.

Figure 1
Classification of 179 normal men and 117 male patients with coronary heart disease in relation to age, predominant clinical manifestations of disease in patients, and positive or negative S-T segment response to maximal exercise. Mean age in years of each group is indicated in parentheses. Note the increasing prevalence of S-T positive (+) response with advancing age in normal men, and presence of angina pectoris in cardiac patients.

Figure 2
Cumulative percentage distribution curves for two groups of normal men and patients with coronary heart disease according to age. Note the marked difference, by selection, between the normals and the close similarity between the patients and older normals who were matched within 1 year of age by experimental design.
Methods

One hundred seventeen (117) men, whose ages ranged from 34 to 73 years with a mean age of 52 years were selected because of a clinical diagnosis of definite coronary heart disease. The diagnosis was based on (1) recurrent exertional chest pain typical of angina pectoris, (2) a Q wave of at least 0.04-sec duration on a resting electrocardiogram, or (3) a clinical episode compatible with acute myocardial infarction substantiated by elevated serum enzymes or myocardial injury recorded on the electrocardiogram, or both. All men were in sinus rhythm, and none were receiving digitalis. No patient was exercised earlier than 2 months following a myocardial infarction.

For comparison, 117 age-matched normal men, whose ages ranged from 33 to 72, with a mean age of 51 years, were chosen from a group of healthy faculty and YMCA volunteers. In addition, a third group of 62 normal young men, whose ages ranged from 15 to 35 years, with a mean of 25 years, were evaluated in the outpatient clinic. Both these groups of men were judged to be normal by history, physical examination, chest x-rays, and 12-lead electrocardiogram. All normal subjects were normotensive according to World Health Organization criteria, with a resting blood pressure of less than 160/95 mm Hg. The clinical categories, numbers of individuals, average ages, and distributions of ECG responses to exercise and ages are presented in figures 1 and 2. Data were also available on 79 of the older normal men who had been tested previously.

The multistage exercise test involves an uninterrupted series of work loads on a motor driven treadmill; the initial submaximal load (stage I) requires walking slowly on a 10% grade. Since there is no increase in oxygen uptake after 3 min of submaximal exertion, the speed and grade are increased every 3 min. Speed and grade for each stage of testing are shown, with mean values for oxygen intake per kilogram of body weight, in table 1. Each person continues exercise until a self-determined end point of exhausting fatigue, marked dyspnea, aching or weakness in the legs, dizziness, chest pain, or various combinations of these.* (Direct measurements of oxygen intake by collecting expired air and performing Scholander gas analyses have averaged from 94 to 95% of maximal oxygen intake—varying with age, disease, and change in physical work load—for 1 min prior to last minute at 100% of maximal effort.) In 32 retests of normals and ambulatory cardiac patients, mean difference in paired measurements of maximal oxygen intake was only 2% of the observed maxima. Since measured maximal oxygen intake, per kilogram of body weight, is highly correlated with duration of exercise with this particular multistage procedure (r = +0.91 for 213 observations), oxygen intake in milliliters per kilogram of body weight per minute may be estimated from the regression equation Y = 3.3 (X - 0.5) + 6.1. Whereas both the subject and the examining physician always monitor performance, the examiner may prematurely stop the test, even in the absence of subjective symptoms, with the onset of either a ventricular arrhythmia (defined as three consecutive ventricular premature beats), or the manifestation of an ataxic gait as presumptive evidence of acute cerebral insufficiency. S-T depression by itself is not cause for stopping the test.

Each subject was examined before and after the test by a physician who remained in attendance during the entire procedure.

A bipolar (CB-5) precordial lead was used to record the electrocardiogram continuously for heart rate, changes in cardiac rhythm, conduction and ST-T forces during exercise, and the first 6 min of recovery. The electrocardiographic tracings were obtained on a Sanborn recorder with an optimally damped amplifier to avoid gross instrumental errors in the low frequency range. The calibration factor was 0.1 mv equal to 1 mm, and the constancy of a sustained signal was verified by a rate of decay less than 5% in 0.2 sec. An ischemic S-T response was defined as S-T segment depression beyond the J point whether upsloping, horizontal, or downsloping, of 1.0 mm or more (less than -0.10 mv) for at least 0.06 sec. Junctional S-T changes were not regarded as abnormal. Heart rates were recorded at rest and during each minute of exercise and recovery,

Table 1

<table>
<thead>
<tr>
<th>Stage</th>
<th>Speed (mph)</th>
<th>Grade (%)</th>
<th>Average O2 consumption required (ml/kg X min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>1.7</td>
<td>10</td>
<td>17.2</td>
</tr>
<tr>
<td>Second</td>
<td>2.5</td>
<td>12</td>
<td>24.5</td>
</tr>
<tr>
<td>Third</td>
<td>3.4</td>
<td>14</td>
<td>34.0</td>
</tr>
<tr>
<td>Fourth</td>
<td>4.2</td>
<td>16</td>
<td>50.0</td>
</tr>
<tr>
<td>Fifth</td>
<td>5.0</td>
<td>18</td>
<td>62.3</td>
</tr>
</tbody>
</table>
while blood pressures were obtained at rest and on initial recovery as well as 3 and 6 min after exertion.

Exercise performance was evaluated by the following parameters of cardiac function: (1) total duration of exertion, (2) maximal heart rate, and (3) maximal systolic blood pressure. In addition, cardiac reserve was judged by (4) change in systolic pressure (maximal systolic blood pressure minus resting systolic blood pressure), (5) heart rate difference (maximal exercise heart rate minus resting heart rate just before exercise), and (6) heart rate reserve (HRR). The latter was derived by relating the submaximal heart rate for stage I to both resting and maximal exercise heart rates, expressed as a percentage as indicated by the formula:

\[
\text{Heart rate reserve} = \left( \frac{\text{maximal HR} - \text{stage I HR}}{\text{maximal HR} - \text{resting HR}} \right) \times 100.
\]

This index represented the percentage of the heart rate difference not utilized for stage I exercise. Resting heart rate and blood pressure were obtained while each subject was sitting just before the start of exercise.

**Results**

**Comparative Exercise Capacity and Circulatory Responses**

Mean duration of exertion was reduced by both advancing age and coronary disease. Whereas young normals were able to exercise for an average of 11.75 min, older normals completed only 9.5 min (\(P < 0.001\)), and

<table>
<thead>
<tr>
<th>Variable</th>
<th>62 young normal men</th>
<th>117 middle-aged normal men (ref. Group)</th>
<th>117 coronary patients</th>
<th>89 anginal patients</th>
<th>28 only healed infarction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>25 ± 6</td>
<td>51 ± 8</td>
<td>52 ± 9</td>
<td>52 ± 10</td>
<td>52 ± 9</td>
</tr>
<tr>
<td>Duration (sec)</td>
<td>705* ± 196</td>
<td>572 ± 108</td>
<td>318* ± 165</td>
<td>293* ± 156</td>
<td>400 ± 171</td>
</tr>
<tr>
<td>Systolic BP (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>132 ± 15</td>
<td>127 ± 17</td>
<td>135† ± 23</td>
<td>135 ± 23</td>
<td>136 ± 19</td>
</tr>
<tr>
<td>Maximal</td>
<td>178 ± 32</td>
<td>182 ± 36</td>
<td>170† ± 28</td>
<td>166* ± 27</td>
<td>183 ± 28</td>
</tr>
<tr>
<td>Change</td>
<td>43† ± 28</td>
<td>55 ± 31</td>
<td>33* ± 23</td>
<td>30† ± 22</td>
<td>43 ± 24</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>80* ± 16</td>
<td>70 ± 10</td>
<td>77* ± 13</td>
<td>76† ± 13</td>
<td>82 ± 12</td>
</tr>
<tr>
<td>Stage I</td>
<td>119* ± 17</td>
<td>107 ± 14</td>
<td>118* ± 16</td>
<td>117 ± 15</td>
<td>122 ± 18</td>
</tr>
<tr>
<td>Maximal</td>
<td>191* ± 12</td>
<td>174 ± 14</td>
<td>142* ± 23</td>
<td>138* ± 22</td>
<td>155 ± 20</td>
</tr>
<tr>
<td>Difference</td>
<td>111† ± 18</td>
<td>104 ± 16</td>
<td>65* ± 21</td>
<td>62* ± 20</td>
<td>75 ± 22</td>
</tr>
<tr>
<td>Reserve (%)</td>
<td>64 ± 13</td>
<td>64 ± 12</td>
<td>33* ± 23</td>
<td>29* ± 22</td>
<td>46 ± 20</td>
</tr>
<tr>
<td>Diastolic BP (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>79* ± 10</td>
<td>84 ± 9</td>
<td>84 ± 12</td>
<td>84 ± 13</td>
<td>87 ± 8</td>
</tr>
<tr>
<td>Maximal</td>
<td>64† ± 15</td>
<td>69 ± 14</td>
<td>87* ± 15</td>
<td>88 ± 15</td>
<td>84 ± 14</td>
</tr>
</tbody>
</table>

* \(P < 0.001\) \(\dagger P < 0.01\) \(\ddagger P < 0.05\).
angina had a duration of 4.9 min, or only 74% of 6.6 min for patients with previous myocardial infarction but no angina.

Changes in heart rate responses were additive. Older normals showed a maximal heart rate of 174 and heart rate difference of 104 beats/min compared to 191 and 111 for younger normals (P < 0.001) (figs. 4 and 5; table 2). Yet both normal groups had an identical heart rate reserve of 64%† (fig. 6; table 2). Thus, older individuals showed lower resting, stage I, and maximal heart rates, but utilized a similar portion of their heart rate difference to perform submaximal work loads.

In contrast, coronary patients exhibited an even lower maximal heart rate (average 142 beats/min), lower heart rate difference (65 beats/min), and a lower heart rate reserve (33%) than either normal group (P < 0.001) (figs. 5 and 6; table 2). Since disease diminished total heart difference, the cardiac patients utilized a greater portion of their heart rate reserve to perform submaximal exercise. Thus, the relative work load on the heart was greater for the patients, even though the absolute physical stress on the body per unit of weight was identical.

Systolic blood pressure was affected differently by aging and coronary disease. Older normals had a slightly higher mean maximal systolic pressure of 182 mm, and greater change in systolic pressure of 55 mm

*Average maximal oxygen intakes, estimated from duration of exercise with this particular test procedure and the regression equation were 43.2, 35.8, and 21.9 ml/kg × min, respectively.

†Available data to assess reproducibility on 79 older normal men who had been tested in the same manner more than 1 year earlier showed correlation coefficients of variables as follows: resting heart rate just prior to exercise, +0.606; at third minute of stage I exercise, +0.623; and at maximal exercise, +0.754. Heart rate difference was +0.542 and heart rate reserve, +0.610. Total duration of exercise was +0.756. Although these variables were highly correlated (P < 0.001), the duration of maximal exercise had the highest reproducibility. Thus there was less variance at a self-determined maximal duration of exercise than at a steady state of only moderate exercise which was controlled by the speed and grade of walking.
Cumulative percentage distributions of heart rate reserve (see text for definition) in normal men and coronary patients. Note that there is no significant difference in this reserve with aging in the normals. Concomitantly, differences from age-matched normals are accentuated in the patients with coronary disease by a marked shift of the curve to the left.

(P < 0.001) than either younger normals or coronary patients (figs. 7 and 8; table 2).

Systemic circulatory adaptations to maximal exercise were also quantitatively different for aging and disease. Young normals showed the greatest exertional vasodilatation with the lowest maximal diastolic pressure of 64 mm. The maximal diastolic pressure of older normals was 69 mm (P < 0.05) (fig. 9; table 2).
Variations in prevalence of S-T segment depression (see text for definition) after maximal exercise in relation to clinical diagnosis and age groups. N represents normal subjects, MI represents patients with healed myocardial infarction, and AP represents patients with angina pectoris. Note the relative independence of age in anginal patients, and the more obvious dependence on age in both normals and patients with prior infarction, but no angina.

Comparison of Postexertional S-T Depression

Normal Men

The prevalence of positive S-T responses after maximal exercise in all 179 normal men was 13% (23 of 179). Its striking age dependence is illustrated in figure 10 where none of 62 younger normals, and only one of 15 normal men of 30 to 39 years of age showed S-T segment depression in contrast to 16 of 66 older men (24%) above the age of 50 years. There was no correlation of postexertional S-T depression with minor ST-T changes in the resting electrocardiogram or elevations in resting blood pressure. In contrast to coronary patients, the frequency of S-T depression in normals increased only with higher cardiac work loads, that is, stages III and IV, or a total exercise duration exceeding 9 min (fig. 11; table 3). Finally, less severe and more transient electrocardiographic patterns were observed in normal subjects. All S-T depressions were upsloping at initial recovery, and none persisted to 3 min after exercise (fig. 12).

Coronary Patients

Postexertional segmental S-T depression occurred in only 59% of coronary patients (69 of 117). The ischemic response associated with disease was more persistent in recovery and often evolved into horizontal and downsloping patterns at 3 min of recovery (fig. 12). While the prevalence of S-T depression increased with advancing years in middle-aged normals and patients with myocardial infarction, age dependence was less marked for coronary patients with only angina pectoris (fig. 10; table 3).

Coronary patients with a history of angina demonstrated a 70% prevalence of ischemic S-T response in contrast to 40% in those with healed myocardial infarction without angina. Of 66 patients developing chest pain while exercising, 80% had positive S-T changes, while only 37% of 51 patients without exertional chest pain showed these changes attributed to ischemia ($\chi^2 = 26$, 1 df, $P < 0.001$). Maximal heart rate, heart rate reserve, as well as maximal systolic pressure and duration of exercise were significantly
### Table 3

**Physiological Responses to Maximal Exercise in Various Patient Groups: Age-Adjusted Means by Covariance Analysis vs Comparable Mean Controls**

<table>
<thead>
<tr>
<th></th>
<th>23 Normal S-T positive</th>
<th>72 Coronary S-T positive</th>
<th>24 Coronary downsloping S-T positive</th>
<th>19 Coronary non-surviving patients*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>94 Normal S-T negative</td>
<td>41 Coronary S-T negative</td>
<td>89 Coronary nondownsloping</td>
<td>79 Coronary survivors</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>54 (50)</td>
<td>54 (50)</td>
<td>56 (52)</td>
<td>57 (51)</td>
</tr>
<tr>
<td>Duration (sec)</td>
<td>615† (561)</td>
<td>309 (321)</td>
<td>319 (312)</td>
<td>307 (314)</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>128 (127)</td>
<td>134 (136)</td>
<td>135 (135)</td>
<td>130 (138)</td>
</tr>
<tr>
<td>Maximal</td>
<td>192 (179)</td>
<td>166 (168)</td>
<td>163 (168)</td>
<td>147† (169)</td>
</tr>
<tr>
<td>Change</td>
<td>65 (52)</td>
<td>32 (36)</td>
<td>27 (34)</td>
<td>23† (33)</td>
</tr>
<tr>
<td>Heart rate resting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage I</td>
<td>70 (70)</td>
<td>76 (77)</td>
<td>73 (77)</td>
<td>78 (76)</td>
</tr>
<tr>
<td>Maximal</td>
<td>107 (107)</td>
<td>118 (118)</td>
<td>117 (119)</td>
<td>118 (119)</td>
</tr>
<tr>
<td>Reserve (%)</td>
<td>181† (172)</td>
<td>139 (147)</td>
<td>134 (144)</td>
<td>138 (144)</td>
</tr>
<tr>
<td>Diastolic BP (mmHg), resting</td>
<td>68 (62)</td>
<td>63 (69)</td>
<td>22† (35)</td>
<td>26 (32)</td>
</tr>
<tr>
<td>Maximal</td>
<td>81 (83)</td>
<td>84 (85)</td>
<td>84 (84)</td>
<td>85 (84)</td>
</tr>
<tr>
<td></td>
<td>61 (69)</td>
<td>85 (87)</td>
<td>83 (87)</td>
<td>86 (85)</td>
</tr>
</tbody>
</table>

* Survival, after exercise test limited to 6 to 60 months in these 19 patients.
† P < 0.05
‡ P < 0.01
lower \((P < 0.01)\) in patients who developed pain on exercise testing.

The influence of ischemic S-T changes on cardiac function was assessed by evaluating the exercise performance of S-T positive coronary patients. Because these subjects were older, covariance analysis\(^{19}\) was employed to eliminate the adverse effect of greater age. Age-adjusted mean values for exercise responses in 72 coronary patients with positive S-T changes were similar to those for 41 coronary patients with negative S-T changes (table 3). Moreover, a subgroup of 24 coronary patients who exhibited the most severe degree of electrocardiographic ischemia (downsloping S-T of 1.0 mm or more at 3 min of recovery) showed the same age-adjusted mean values for performance as 89 other coronary patients (table 3).

Although most coronary patients exercised subnormally in comparison with age-matched normals, a small number of patients with an-
Table 4

Prevalence of S-T Segment Depression in Older Males in Relation to Other Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>All normal subjects</th>
<th>All coronary patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Criteria</td>
</tr>
<tr>
<td>Age</td>
<td>1/77</td>
<td>&lt;40 yr</td>
</tr>
<tr>
<td></td>
<td>16/66</td>
<td>&gt;50 yr</td>
</tr>
<tr>
<td>Systolic pressure</td>
<td>2/18</td>
<td>&gt;144 mm Hg</td>
</tr>
<tr>
<td></td>
<td>21/99</td>
<td>≤144 mm Hg</td>
</tr>
<tr>
<td>Diastolic pressure</td>
<td>1/13</td>
<td>&gt;93 mm Hg</td>
</tr>
<tr>
<td></td>
<td>21/99</td>
<td>≤93 mm Hg</td>
</tr>
<tr>
<td>Resting ECG</td>
<td>20/97</td>
<td>WNL</td>
</tr>
<tr>
<td></td>
<td>3/20</td>
<td>ST-T changes (nonspecific)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise duration</td>
<td>34</td>
<td>≤9 min</td>
</tr>
<tr>
<td></td>
<td>83</td>
<td>&gt;9 min</td>
</tr>
<tr>
<td>History of angina</td>
<td>10/25</td>
<td>Absent</td>
</tr>
<tr>
<td></td>
<td>62/80</td>
<td>Present</td>
</tr>
<tr>
<td>Chest pain with</td>
<td>19/51</td>
<td>Absent</td>
</tr>
<tr>
<td>exercise test</td>
<td>53/66</td>
<td>Present</td>
</tr>
<tr>
<td>Follow-up status</td>
<td>47/79</td>
<td>Alive</td>
</tr>
<tr>
<td></td>
<td>16/19</td>
<td>Expired</td>
</tr>
</tbody>
</table>

Abbreviations: WNL = within normal limits; LAD = left axis deviation; LVH = left ventricular hypertrophy; LVS = left ventricular strain; LVI = left ventricular ischemia.

Gina, infarction, or both, did well. For those whose duration was more than 9 min (stage IV), with maximal heart rates greater than 160 beats/min, and change in systolic pressure over 50 mm Hg, the frequency of ischemic S-T changes was less than that for the entire group (table 4).

Finally, in the coronary patients electrocardiographic items (at rest) indicative of left ventricular disease were predictive of postexercise S-T segment depression. Of 12 coronary patients demonstrating left ventricular hypertrophy, ischemia, strain, or left axis deviation, all showed this ischemic response after maximal exercise. Conversely, patients with resting systolic pressures over 158 mm or diastolic pressures over 96 mm (more than 1 standard deviation above the respective means) showed no increased frequency of positive S-T changes (table 4).

Prognosis of Coronary Patients

To date, 19 of 117 coronary patients have died, and 79 patients have survived from 6 to 60 months after exercise testing; the status on the remaining 19 patients is unknown. At the time of testing, the deceased had a mean age of 57 years, whereas the survivors averaged 51 years of age. The deceased had a mean survival of 23 versus 33 months for those who are still living. Because of the significant difference in age when they were tested, exercise data were age adjusted by covariance analysis. The deceased patients had lower maximal systolic pressure, and lower change in systolic pressure than the survivors (P<0.05). The prevalence of S-T segment depression was also greater in the deceased (x^2 = 3.9, P = 0.05). Possibly a more reliable assessment of prognostic power will be obtained when the proportion of deceased and surviving patients is equalized in the future.

Discussion

Maximal exercise with a multistage treadmill test has clearly demonstrated impaired cardiovascular function in the majority of patients with coronary heart disease. While a few patients exercised normally for their ages, most responded inadequately to the stress of
maximal work loads. Thus, maximal duration and maximal oxygen consumption were significantly reduced. These findings are consistent with the results of other investigators employing a variety of test procedures. Malmberg,\textsuperscript{1} utilizing a bicycle ergometer, showed a significantly lower maximal exercise tolerance in 38 coronary patients than in 11 normal middle-aged men. Moreover, patients whose tolerance was equal to, or greater than, 600 kpm/min (kilopound meters/min) demonstrated significantly larger stroke volumes and lower ventricular filling pressures than more impaired patients.

Normal cardiac outputs at both rest and moderate exertion with either treadmill or stair climbing have been reported in survivors of myocardial infarctions.\textsuperscript{20, 21} Yet Bolt and associates\textsuperscript{22} have shown that only one third of these patients could achieve a maximal oxygen consumption of 1.8 to 2.0 L/min. Furthermore, while studying the energy requirements of the Master two-step test, Ford and Hellerstein\textsuperscript{23} noted an abnormal pattern of oxygen consumption for many coronary patients. Ability to increase oxygen utilization was reduced during exercise, and a greater part of the oxygen consumption was delayed to the recovery period. The authors interpreted these findings to mean insufficient cardiac output with reduced oxygen delivery to exercising muscles. Moreover, in recovery, the cardiac output or the arteriovenous oxygen differences, or both, must remain elevated for a longer period to compensate for oxygen not delivered during exertion.

The present study documents impaired exercise performance at both submaximal and maximal work loads of patients with coronary heart disease. Quantitatively the effects of disease are more marked in patients with angina than in those who survived acute myocardial infarction. In both types of patients, heart rate was faster, at the lowest submaximal work load which was used, than that of age-matched controls. Accordingly, the heart rate reserve was lower, especially in patients with angina who also exhibited the lowest maximal heart rates. Thus, the relative stress on the myocardium was augmented, even though the external physical work load on the body was identical to that of the controls. This distinction could not be fully appreciated from the absolute values observed at submaximal exercise since maximal effort must be defined for the individual before the relationship of submaximal to maximal can be determined. At maximal exercise duration, estimated maximal oxygen intake, maximal heart rate, heart rate difference, maximal systolic pressure, and change in systolic pressure were all significantly lower than observed in age-matched controls. Whereas it might be argued whether these differences were simply due to stopping exercise prematurely for other reasons, the intensity of the symptoms, the delayed recovery after exertion, and the objective evidence of little increment in oxygen intake during the last 2 min of exercise in a few patients in whom this was carefully measured clearly indicate that a nonphysiological limitation is untenable. Other studies, now in progress, on cardiac output and pulmonary arterial and aortic pressures indicate that altered hemodynamic responses occur well before, rather than after the subjective awareness of angina or other symptoms.\textsuperscript{24} Thus, there is indirect evidence from the present studies of circulatory impairment of oxygen transport due to both impaired contractile force and heart rate difference. The significantly lower maximal systolic pressure, as well as reduced change in systolic pressure, reflect impaired myocardial contractility and a deficient stroke output. These findings agree with those of other investigators who demonstrated inadequate rises in stroke volume, stroke work, and mean systolic ejection rate.\textsuperscript{3, 4, 6} Depressed left ventricular function was most readily apparent during episodes of coronary insufficiency.\textsuperscript{1, 3, 5}

Impaired chronotropic responses of coronary patients were evident by a greater reduction in maximal heart rate, heart rate difference, and lower heart rate reserve (HRR). Consequently, since submaximal work loads required a greater portion of that capacity, they proved to be relatively more
stressful for the myocardium of coronary patients than for normal subjects.

Among coronary patients not in heart failure and not receiving digitalis, those with angina were more disabled than those having only healed myocardial infarction. Total duration, maximal systolic blood pressure, change in systolic pressure, maximal heart rate, and heart rate reserve, all were significantly lower in angina patients. These results are consistent with several studies which have associated angina with the presence of more severe left ventricular insufficiency.\textsuperscript{1,2,5} Left ventricular end-diastolic, pulmonary wedge, and pulmonary artery pressures were significantly elevated while stroke volume, stroke work, and systolic ejection rate were reduced during episodes of angina.\textsuperscript{1,2,5}

In contrast, studies of coronary patients without angina show a state of left ventricular function intermediate between that of normals and anginal patients. Parker and associates\textsuperscript{25} noted, in 15 patients with healed myocardial infarctions, a spectrum of exercise responses varying from normal to one of marked left ventricular impairment indistinguishable from that of patients with exertional angina. Messer and co-workers\textsuperscript{1} found that patients with coronary disease, but without angina, had reduced cardiac output, stroke volume, and mean systolic ejection rate when compared to normals, but better function than that of anginal patients. These hemodynamic studies are in accord with the experience at work evaluation clinics where the majority of postinfarction survivors can be re-employed, except for those with either heart failure or significant angina pectoris.\textsuperscript{26,27}

The diminished exercise performance that accompanies advancing age in normal subjects is further documented in this study. Changes resulting from reduced myocardial compliance resemble those of disease, but distinctly

### Effects of Aging versus Coronary Heart Disease on Maximal Exercise Performance

*Kasser and Bruce, 1968*

**Figure 13**

Average percentage differences in exercise performance (duration), changes in heart rate, systolic and diastolic blood pressures, and prevalence of S-T segment depression after maximal exercise attributable to aging in normal men, and to coronary heart disease in men of comparable age. Note the greater decrements in duration, heart rate, and systolic pressure with coronary disease, along with a positive diastolic pressure difference due to compensatory vasoconstriction. The ischemic ECG response is also more common in patients with coronary disease.
different patterns do exist (fig. 13). Middle-aged normal men showed lower total duration of exercise and lower maximal heart rates than younger normal men without any apparent difference in heart rate reserve. These findings point to a limited overall capacity, with normal adaptation to lower work loads. On the other hand, the greater reductions in duration, maximal heart rate, and heart rate reserve of patients with coronary disease demonstrate impaired exercise performances at both submaximal and maximal levels. Other studies have also reported that aging affects stroke volume, heart rate, and cardiac output more at higher than at lower work loads in normal individuals.11,12

Blood pressure responses to maximal exercise are quite different for older normal persons and diseased patients. Despite reduced maximal systemic blood flow, the altered elastic properties of aging vessels augment peripheral systolic blood pressure (fig. 13). In contrast, patients with coronary disease have a lower maximal systolic pressure and lower change in systolic pressure, when compared to age-matched normals, due to insufficient stroke output even in the presence of aging vessels which increase maximal systolic pressures. That the reduction in cardiac output with disease is greater than that of aging can be inferred from differences in total duration of exercise for the three groups. Among normals, advancing age reduces duration by 2½ min, while coronary disease lowers the duration by more than 4 min.

Maximal diastolic pressures likewise respond in a predictable manner. Young normals with the highest cardiac outputs and least vascular changes displayed the most vasodilation. Older normals whose output was somewhat reduced and whose vessels were more rigid showed higher maximal diastolic pressures. Finally, coronary patients who had the greatest reduction in cardiac output demonstrated the most vasoconstriction with an increase in diastolic pressure during maximal exertion (fig. 13).

Serious diagnostic and prognostic implications of postexercise S-T depression have been documented by several studies. Robb and Marks28 who evaluated 2,224 male life insurance applicants with Master's two-step test, found the mortality from coronary artery disease to be eight times higher in those showing ischemic changes. The mortality increased rapidly with the amount, type, and extent of ischemic responses. That is, patients with downsloping S-T depression of 2.0 mm or more displayed on multiple electrocardiographic leads had a considerably worse prognosis than horizontal S-T depression of less than 1.0 mm on a single lead.

Mattingly29 demonstrated a significantly higher mortality from coronary disease in patients showing 0.5 mm or more S-T depression. Postmortem data on 47 patients who died within 6 years after performing Master's two-step test showed electrocardiographic findings to be more specific than sensitive when other causes of ischemia could be eliminated. Thus, of 17 patients with little atherosclerotic coronary disease (grade 2 or less), only one patient (6%) suffering from a chronic aplastic anemia had shown a “false positive” S-T response. Since 17 of 30 patients with significant coronary atherosclerosis (grade 3 or 4) exhibited prior ischemic S-T changes, the sensitivity for true positives was 57%. Incidence of false positives was 6% and of false negatives, 43%, while specificity for true negatives was 94% ($x^2 = 5.6$, 1 df, $P < 0.05$).

False positive, and particularly, false negative S-T changes have continued to be a problem even with more strenuous exercise. Mason and associates30 compared coronary arteriographic findings with S-T responses of near maximal exertion, using either an escalator or bicycle ergometer. Of 42 patients with a positive S-T response (1.0 mm or more), 38 showed important narrowing of coronary vessels. Conversely, of 42 patients with a negative S-T response, 31 had less than 50% narrowing. Here, the frequency of false positives was 9.5%, and false negatives, 26%. The authors concluded that other factors associated with false negative S-T responses may be the small size of the ischemic area.
and possibly the presence of collateral circulation.

The data from the current study suggest that postexertional S-T depression may occur in a variety of circumstances and should not simply be equated with severe coronary occlusive disease. Among normal subjects, both increasing age and unusually high cardiac work loads predispose to S-T changes. While no ischemic changes occurred below the age of 35, the prevalence rose sharply to 26% above the age of 50. These findings agree with the frequency of S-T responses reported by Doan and associates in 433 asymptomatic men. Furthermore, S-T positive normal men actually performed “supernormally” when compared to S-T negative normals, showing longer (by covariance analysis to adjust for older age) total duration, higher maximal heart rate, and greater change in systolic pressure. Although these S-T positive normals may have occult coronary disease, their superior exercise performance contradicts this assumption. Rather, it appears that the myocardium of older persons can be made transiently ischemic only if the cardiac stress is sufficiently great, even in the absence of significant coronary occlusive disease. Similarly, it has been shown that the combination of hypoxic and exertional stresses in normal young men elicits S-T depression when neither alone will do so. Confirmation of occlusive vascular disease will require either arteriographic evaluation or longer follow-up studies, or both, to exclude the possible role of latent disease in these individuals.

Conversely, the presence of severe coronary disease does not mean that S-T depression will always occur with exercise. While coronary arteriographic studies in this laboratory have demonstrated a close association of ischemic S-T changes with diffuse occlusive disease and

![Figure 14](image)

*Figure 14*

Example of change from borderline positive ECG response after standard multistage exercise test (on the left) to distinctly positive response 3 min after exertion (on the right) in a patient with coronary heart disease. Bipolar precordial tracings recorded immediately after maximal exertion (upper row) and again 3 min later in recovery (lower row). In the second instance (on the right) the initial work load was reduced to walking on a 5% grade for 3 min prior to usual first stage at 10% and 1.7 mph. Total duration of exertion before stopping for angina was 283 sec (on the left) and 307, or 24 sec longer (on the right). Despite the slower heart rate (122 versus 160) and lower systolic pressure (172 versus 192) with the second test, horizontal S-T depression was well developed at 3 min.
significant collateral vessels, the minority of severely diseased patients still remains S-T negative.32 The explanation of this phenomenon may lie in the nature of the test procedure. The initial stage of the multistage treadmill test is actually so stressful for some severely impaired coronary patients that they are unable to exercise for a sufficient period to impose an adequate work load on their myocardium. Actually the frequency of S-T depression increases in patients with angina as the number of stages increases from I to II (fig. 11). Thus, even in the face of diffuse severe coronary disease, a threshold of hemodynamic stress on the myocardium must be reached. Figure 14 illustrates how a positive S-T response could be induced in patient D.R. by altering the usual test procedure to provide a longer period of exertion at an even lower work load and thereby augmenting the total work load.

In conclusion, the postexercise S-T response is the result of a variety of factors affecting the balance between the work load imposed and the oxygen available to the myocardium. S-T depression may occur in both diseased and healthy subjects, depending on age, cardiac stress, and patency of coronary vessels or adequacy of oxygen transport of the myocardium. The clinical expression of S-T depression in disease, however, is a more prolonged, severe, symptomatic, and evolving force after exertion than that seen transiently in clinically normal individuals.

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