Studies of Electrocardiographic Changes during Exercise (Modified Double Two-Step Test)

By Paul N. G. Yu, M.D., and Alfred Soffer, M.D.

A method of recording electrocardiograms during the performance of a double two-step exercise test is described. Data obtained from 32 normal subjects and 54 patients are analyzed, and changes in heart rate, S-T segment, T wave and Q-T interval and the occurrence of premature beats described. Criteria for an abnormal response indicating coronary insufficiency are defined. This method retains the merits of Master's original test and in addition has several distinct advantages.

Studies of the electrocardiogram during and after exercise (walking on a treadmill ergometer at standard speed and grade) in normal subjects have shown a definite pattern of change in the Q-T interval and no evidence of coronary insufficiency.1 2 On the other hand, a large percentage of patients with various cardiopulmonary diseases showed definite and striking abnormal changes.

Since Master's "two-step" test2 4 has been widely used in different clinics, similar studies of the electrocardiogram during exercise were undertaken with modification of the original method. It is the purpose of this report to describe the procedure and to present the results obtained in 32 normal subjects and 54 patients with various cardiovascular disease. These studies suggest that the modified method can be used wherever the exercise electrocardiogram is indicated and that it contributes significantly to its sensitivity and safety.

Method

An exploring precordial electrode connected with the chest wire was placed over the fifth intercostal space along the left midclavicular line or slightly to its left. An indifferent electrode connected with the left leg wire was placed just below the tip of the right scapula. A third electrode connected with the right leg wire, placed over the right precordium, served as the ground. The exploring and indifferent electrodes constitute the so-called "CB," lead which was first introduced by Wollereth and Wood3 and later modified by Lieberson and Liberson.9 All three electrodes were tightly applied to the chest wall by a rubber chest strap8 so that during exercise there was no change in the position of the electrodes. The control knob was switched to CF to record lead CB4 or CB5.

A portable direct-writing electrocardiograph (Edin) was used throughout the study. Changes in the electrocardiogram during and after exercise could be observed minute by minute. Lead CB4 was standardized so that 1 mv. caused a deflection of 10 mm. If the QRS complex was too high, it was standardized at a deflection of 5 mm. per millivolt.

A short strip of lead CB4 was taken before the exercise was performed. If the R wave was low and S wave deep (rS), the precordial electrode was moved further to the left until an Rs, or qRs complex was obtained. (Depression of the S-T segment is usually more marked with a high R wave than with a deep S wave, because the presence of a high R wave indicates that the electrode is facing the left ventricular surface.) The subject was instructed to take several deep inspirations and expirations while a tracing was being recorded. Marked shifting of the baseline or muscular interference indicated the need for tightening of the rubber chest strap and reapplication of the electrode paste. During exercise the baseline often wandered slightly due to respiratory movement. In some women it was necessary to place the exploring electrode in the anterior axillary line (CB6) in order to obtain full phase contact of the electrode.

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* Obtained from Sanborn Company, Cambridge, Mass.
The performance of the step test was the same as that described by Master and associates\(^3\) except for the following modifications: (a) The CB\(_4\) or CB\(_3\) lead was used throughout the test and no tracings from limb leads were made. (b) A double two-step test lasting three minutes was performed on every subject unless it was interrupted by the appearance of symptoms or marked electrocardiographic abnormalities. (c) The tracings were made at rest, at the end of each minute during exercise, 30 seconds, 90 seconds, and 150 seconds after termination of exercise and 8 minutes after exercise or later.

The test was arbitrarily divided into four periods: (1) Resting—before exercise, (2) Exercise—three minutes or less. (3) Early recovery—first three minutes of recovery. (4) Late recovery—eighth minute of recovery or later.

The heart rate was obtained by measuring the number of QRS complexes in a period of six seconds and multiplying by 10. Depression or elevation of the S-T segment was measured from the iso-electric level (P-R or P-Q level). It was essential to measure three or four beats on a horizontal level in order to avoid simulation of S-T depression or elevation by a wandering baseline. The amplitude of the T wave was measured from the baseline to the peak of the wave in each individual complex. If there was distinct variation of the amplitude of the T wave, the average of the amplitude of an equal number of high and low T waves was recorded. Usually three or more consecutive Q-T intervals and corresponding cycle length were measured to the nearest 0.05 second. Their average values were used to compute the Q-T/T-Q ratio and the corrected Q-T interval (Q-T\(_c\)). The T-Q interval is the difference between the cycle length and its Q-T interval. The corrected Q-T interval (Q-T\(_c\)) was calculated from the modified Bazett's formula:\(^7\)

$$\text{Q-T}c = \frac{\text{Q-T interval}}{\sqrt{\text{cycle length}}}$$

### RESULTS IN NORMAL SUBJECTS

Thirty-two normal individuals between ages 21 and 66 years served as controls. They were mainly physicians, medical students, nurses, and technicians. There were 26 males and 6 females. None had a history of cardiovascular disease. Each had a normal physical examination and resting electrocardiogram. A roentgenogram of the chest was obtained in most of the subjects and was normal in each instance. Changes in the heart rate varied greatly in different individuals. The maximum heart rates during exercise and early recovery were, respectively, 158 and 125 per minute, and these were recorded in the same subject. The heart rate returned to within 10 points of the resting value during the second minute of recovery in 25 of the 32 normal subjects. In several subjects the heart rate was the slowest in the second minute of recovery.

The Q-T/T-Q ratio at rest was usually less than 1. It always increased during exercise and promptly returned to the resting value before the third minute of recovery. In none of the normal subjects did the Q-T/T-Q ratio exceed 2 during exercise. The increase in average exercise Q-T/T-Q ratio was usually less than 100 per cent of the average resting value.

The pattern of changes of the Q-T, interval was the same as that observed in treadmill walking, that is, prolongation during exercise, shortening during early recovery and return to the resting value during late recovery.\(^1\) The Q-T\(_c\) interval was usually highest in the first minute of exercise. In no case during exercise did the Q-T\(_c\) interval decrease below the average resting value. Shortening of the Q-T\(_c\) interval during early recovery was definite, especially during the second minute of recovery.

There was no significant change in the P wave during and after exercise. Some individuals showed slight decrease in the amplitude of the R wave and a concomitant deepening of the S wave during exercise. The T wave became lower or remained unchanged during exercise in all of the instances, while in some subjects it increased slightly during early recovery. High T waves during exercise or early recovery, with an increase in amplitude of more than 50 per cent of the resting value, were not observed. Slight S-T depression of less than 1 mm. during or immediately after exercise occurred in four subjects. In a great majority of normal subjects the S-T segment remained iso-electric throughout the test. In two normal subjects a slightly elevated S-T segment at rest became iso-electric during and after exercise. We agree with Master\(^4\) that this change should be considered as normal, unless the depression is below the iso-electric level. No S-T elevation has ever been noted in normal controls. None of the normal...
subjects showed ventricular premature beats, auriculoventricular or intraventricular block, or the appearance of a Q wave during or after exercise.

Typical tracings of control subjects with normal response to exercise are illustrated in figure 1. The composite data of the heart rate, iso-electric, or from inverted to upright). (b) Increase in the amplitude of the T wave greater than 50 per cent of the resting value. (3) Q-T/T-Q ratio of more than 2.2 during exercise. (4) Shortening of the QTc interval during exercise or prolongation of QTc interval during early recovery. (5) The appearance of ventricular premature beats during exercise or early recovery.

We have not encountered intraventricular or auriculoventricular block.

Table 1.—The Heart Rate, Q-T/T-Q Ratio, and Q-Tc in 32 Normal Subjects

<table>
<thead>
<tr>
<th>Period of Observation</th>
<th>Heart Rate Per Minute</th>
<th>Q-T/T-Q</th>
<th>Q-Tc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td>78</td>
<td>0.90</td>
<td>.408</td>
</tr>
<tr>
<td>Exercise</td>
<td>57-98</td>
<td>.62-.1.17</td>
<td>.358-.453</td>
</tr>
<tr>
<td>1st minute</td>
<td>114</td>
<td>1.58</td>
<td>.441</td>
</tr>
<tr>
<td>2nd minute</td>
<td>79-140</td>
<td>.81-.2.00</td>
<td>.367-.500</td>
</tr>
<tr>
<td>2nd minute</td>
<td>124</td>
<td>1.61</td>
<td>.430</td>
</tr>
<tr>
<td>3rd minute</td>
<td>102-150</td>
<td>1.03-.2.00</td>
<td>.384-.481</td>
</tr>
<tr>
<td>Early recovery</td>
<td>107-158</td>
<td>1.16-.2.00</td>
<td>.372-.454</td>
</tr>
<tr>
<td>1st minute</td>
<td>98</td>
<td>1.02</td>
<td>.393</td>
</tr>
<tr>
<td>2nd minute</td>
<td>73-125</td>
<td>0.60-.1.40</td>
<td>.342-.431</td>
</tr>
<tr>
<td>3rd minute</td>
<td>80</td>
<td>0.90</td>
<td>.400</td>
</tr>
<tr>
<td>3rd minute</td>
<td>54-109</td>
<td>0.54-.1.20</td>
<td>.369-.442</td>
</tr>
<tr>
<td>Late recovery</td>
<td>83</td>
<td>0.92</td>
<td>.405</td>
</tr>
<tr>
<td>8th minute</td>
<td>55-116</td>
<td>0.56-.1.36</td>
<td>.367-.456</td>
</tr>
<tr>
<td>10th minute</td>
<td>83</td>
<td>0.97</td>
<td>.415</td>
</tr>
<tr>
<td>10th minute</td>
<td>60-108</td>
<td>0.60-.1.38</td>
<td>.360-.456</td>
</tr>
<tr>
<td>10th minute</td>
<td>82</td>
<td>0.95</td>
<td>.409</td>
</tr>
<tr>
<td>10th minute</td>
<td>66-113</td>
<td>0.64-.1.36</td>
<td>.375-.448</td>
</tr>
</tbody>
</table>

Results in Patients

Fifty-four patients ranging in age from 18 to 69 years were studied. There were 35 males and 19 females. They were classified in three main groups according to diagnosis. (a) Group I—21 patients with a typical history of angina pectoris. (b) Group II—21 patients with arteriosclerotic and hypertensive heart diseases (ASHD and HCVD) who had no history of angina. (c) Group III—12 patients with miscellaneous diseases including five with rheumatic heart disease, two with congenital heart disease, two with intermittent
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claudication, two with atypical chest pain and two with abnormal ballistocardiogram.

The resting electrocardiogram was normal in each instance except for minimal T wave abnormalities in six patients and slight S-T depression in one patient. Eleven patients in group I and four patients in group II did not complete the double two-step test because of precordial pain, severe dyspnea, or marked electrocardiographic changes. At least one exercise electrocardiogram was recorded for each patient. Two or more exercise tests were performed at regular intervals on nine patients.

**Pulse and Q-T Changes**

The average value and range of the heart rate, Q-T/T-Q ratio, and Q-T₁ interval during rest, exercise and recovery are presented in table 2. The over-all heart rate in the corresponding minutes was higher in the patients than in the normal subjects. During exercise the heart rate of 15 patients exceeded 158 per minute which is the maximum rate obtained in the normal subjects. The heart rate failed to return to within 10 points of the resting value during the second minute of recovery in more than 75 per cent of the patients.

![Figure 2](https://example.com/image.png)

**FIG. 2.** J. S. A 58 year old woman with severe hypertension and history of angina pectoris. Note definite S-T depression during exercise which is less distinct during early recovery. There is also a significant increase in the amplitude of the T wave during both exercise and early recovery. J. D. A 44 year old man with typical history of angina pectoris. Note significant increase in the amplitude of the T wave during exercise and early recovery. The Q-T/T-Q ratio during exercise exceeds 4.0. Distinct S-T depression occurs during the first three minutes of recovery. V. B. A 54 year old woman with no evidence of cardiovascular disease. Although the increase in the heart rate during exercise (158 per minute) is comparable with that in case J. D., yet the Q-T/T-Q is less than 2.0. Furthermore, no significant changes in either the T wave or the S-T segment were observed.

The average Q-T/T-Q ratio in the corresponding minutes was higher in the patients than in the normal subjects. In 23 patients
the Q-T/T-Q ratio was more than 2.2 in one of the three minutes of exercise. In several patients who showed marked symptoms and distinct electrocardiographic changes, the exercise Q-T/T-Q ratio reached 4 or 5 (fig. 2, J. D.). Although the averaged Q-Te interval was prolonged during exercise, it did not shorten during early recovery. This abnormal response was observed in almost half of the patients.

Table 3.—Incidence of Abnormal Changes During Exercise and Recovery in 54 Patients

<table>
<thead>
<tr>
<th></th>
<th>S-T Depression</th>
<th>Changes in T Wave*</th>
<th>Abnormal Q-T/ T-Q Above 2:1</th>
<th>Abnormal Q-Ta</th>
<th>Ventricular Premature Beats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>During Exercise only</td>
<td>During Recovery only</td>
<td>During Exercise and Recovery</td>
<td>During Exercise only</td>
<td>During Recovery only</td>
</tr>
<tr>
<td>GROUP I</td>
<td>Angina Pectoris (21 cases)</td>
<td>5 2 10</td>
<td>4  2 inverted 2 high</td>
<td>—</td>
<td>6 3 paradoxical 2 inverted 1 high</td>
</tr>
<tr>
<td>GROUP II</td>
<td>ASHD (non-angina) (21 cases)</td>
<td>— 4 8</td>
<td>2 2 high</td>
<td>—</td>
<td>5 5 diphasic or inverted</td>
</tr>
<tr>
<td>GROUP III</td>
<td>Miscellaneous (12 cases)</td>
<td>1 1 —</td>
<td>1 1 high 1 diphasic</td>
<td>—</td>
<td>3 3 1</td>
</tr>
</tbody>
</table>

* Inverted—from an upright to an inverted T wave.
High—from an upright to a high T wave.
Diphasic—from an upright to a diphasic T wave.
Paradoxic—from an inverted to an upright T wave.

S-T and T Changes

The incidence of the abnormal electrocardiographic changes observed in 54 patients is summarized in table 3.

Of 21 patients in group I, abnormal S-T depression was recorded only during exercise in five (figs. 3 and 4, S. G.), only during recovery in two and during both exercise and recovery in 10 (fig. 5). Four patients showed abnormalities in the T wave only during exercise: two with inversion of the T wave (fig. 4, M. T.) and another two with the development of high T waves (fig. 6). T-wave changes occurred during both exercise and recovery in six patients (figs. 2, 6). Ventricular premature beats occurred during exercise and recovery in three patients. In one patient multiple premature ventricular beats developed during the first minute of exercise and the patient did not complain of precordial pain until the end of the third minute (fig. 7).

Of the 21 patients in Group II, four showed distinct S-T depression during recovery and not during exercise, and eight exhibited similar changes both during exercise and recovery. Two patients had significantly high T waves during exercise and five patients showed either an inverted or diphasic T wave during both exercise and recovery. Ventricular premature beats were registered during exercise and recovery in one patient.

In group III the incidence of S-T and T-wave abnormalities was low. One patient showed abnormal S-T depression and another high T waves only during exercise. The third patient had S-T depression and diphasic T waves only during early recovery.

Abnormalities of the S-T segment and T wave which developed during exercise usually persisted through the first three minutes of recovery and returned to the resting pattern by the eighth minute of recovery.
Elevation of the S-T segment occurred in one case during exercise and early recovery. The case is not included in this series. Pro-two-step test has been reported. Movements of the extremities preclude recording any satisfactory tracings during exercise by using Master's original method. With precordial lead (CB4 or CB5) it is possible to record the electrocardiogram during exercise without difficulty or interference. Most investigators agree that the precordial lead is more sensitive than any of the three standard limb leads.4, 8–10.

![Fig. 3. F. B. A 37 year old man with history of angina pectoris. He did not complain of any precordial pain during both double two-step tests. Note marked S-T depression during exercise on 3/9/50 and less marked S-T depression during exercise on 6/6/50. In either instance the changes are not significant during recovery. This case illustrates three points: (1) No constant parallel exists between precordial pain and electrocardiographic abnormalities. (2) Changes indicative of coronary insufficiency may occur only during exercise and not after exercise. (3) Similar changes may be reproduced even after a period of three months.](image)

![Fig. 4. S. G. A 59 year old man with history of angina pectoris and also evidence of anemia. He was unable to exercise for more than two minutes because of precordial pain and dyspnea. The electrocardiogram shows distinct S-T depression only during exercise and not after exercise. M. T. A 57 year old man who had had an attack of anterior myocardial infarction five years ago and since then frequently complained of precordial pain after exertion. The CB4 lead shows a low T wave which becomes inverted only during the second and third minutes of exercise. Note the upright T wave in the recovery period.](image)
This is understandable according to the principle that "regions close to the exploring electrode influence the pattern obtained to a greater degree than do areas remote from it."11

The potential of the right scapular region, on which the indifferent electrode is placed, varies through a relatively small range.11

Other investigators4, 8, 12 have pointed out that the double two-step test demonstrates abnormalities in many patients in whom the electrocardiogram is normal in the standard

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**Fig. 5.** K. S. A 39 year old man with typical history of angina pectoris. Patient died of an attack of acute myocardial infarction two weeks after this test was performed. P. A. A 56 year old man with typical history of angina pectoris.

The exercise electrocardiogram in these two cases shows marked depression of the S-T segment during both exercise and recovery. Note that the S-T depression actually occurs early in the first minute of exercise.

**Fig. 6.** E. P. A 59 year old man with typical history of angina pectoris. On 4/12/50 he was able to exercise for only two minutes because of dyspnea and precordial pain. The exercise electrocardiogram shows a so-called paradoxical response. The diphasic or inverted T wave at rest becomes upright during exercise and early recovery. After dietary management for a period of six months, his condition was improved and his precordial pain was less frequent. On 10/20/50 another exercise test was performed. This time he completed the double two-step test with only slight discomfort, and the resting electrocardiogram (lead CB4) shows an upright T wave. During the second and third minutes of exercise, there is a distinct increase in the amplitude of the T wave associated with S-T depression. Both the paradoxical response and increase in the amplitude of T wave are the result of subendocardial ischemia.
Electrocardiographic Changes During Exercise

For this reason, we used the double two-step test as standard procedure in our study. If severe symptoms develop or if marked abnormalities appear in the electrocardiogram, the test may be interrupted immediately. Indeed, unlimited exertion in order to produce pain may be hazardous. In some cases electrocardiographic abnormalities may occur without symptoms, since no constant parallel exists between pain and electrocardiographic changes.

Abnormal findings in the exercise electrocardiogram have been demonstrated in normal subjects under unusual stresses. Therefore, we believe that any exercise for the diagnosis of coronary insufficiency should be standardized.

Changes of heart rate may be observed by taking electrocardiogram during the exercise period. The average heart rate during exercise was considerably higher in the patients than that in the normal subjects for the corresponding minute. Furthermore, the heart rate in at least one of the three minutes of exercise exceeded the maximum rate recorded in the normal subjects in 15 of the 54 patients.

Changes of the Q-T interval in normal subjects performing the double two-step test have been uniform and consistent. The Q-T/T-Q ratio during exercise was always less than 2.2 no matter what the heart rate. In some patients the ratio reached 4 or 5 and these values were associated with a very rapid heart rate. The Q-T/T-Q ratio is closely related to, but not entirely dependent upon, the heart rate. Therefore, both heart rate and Q-T/T-Q ratio may be a very useful index in determining myocardial function: The more rapid the rate, the higher the Q-T/T-Q ratio and the poorer the function.

The significance of changes in the Q-T interval in patients with coronary insufficiency requires further study.

This study demonstrates that abnormal electrocardiographic changes such as S-T depression, alteration of the T wave and appearance of ventricular premature beats actually occurred during exercise and persisted to the recovery period in most cases. These changes are frequently diagnostic, and abnormalities occurring during exercise may be the only indication of coronary insufficiency. Our results show that false negative tests may be obtained in about 20 per cent of the cases of angina pectoris, if tracings are not made during exercise.

It should be noted, however, that electrocardiographic abnormalities indicating coronary insufficiency may be seen during and after exercise in patients without angina pectoris.

Recent experimental and clinical studies have shown that S-T depression in the precordial leads is due to injury in the subendocardial layer of myocardium. Inversion of an upright T wave in the precordial leads is probably due to a lesion of the epicardial surface, and reversion of an inverted or diphasic T wave is a good diagnostic sign of angina pectoris.

![Figure 7](http://circ.ahajournals.org/figure/7)

**Figure 7.** The patient is a 52 year old woman who manifests classic symptoms of angina pectoris. Beginning in the recovery period the patient experienced somewhat marked though temporary symptoms, but note that an arrhythmia is recorded earlier than this in the second minute of exercise. A—Rest, B, C and D—Exercise, E, F and G—Early recovery, H—Late recovery.
wave (paradoxical positive T wave change) in the same leads may be an indication of endocardial injury with "delayed repolarization." Experimental evidence also indicates that minor injury to the subendocardial myocardium may result in an increase in the amplitude of an upright T wave.\textsuperscript{11, 20} We believe that the abnormal increase in the amplitude of an upright T wave during exercise is significant in human subjects. This change may be an indication of early subendocardial ischemia. An upright T wave in the precordial leads of some patients may increase in amplitude (suggesting subendocardial ischemia) earlier than or in association with the classic depression of the S-T segment indicating subendocardial injury due to coronary insufficiency.

**SUMMARY AND CONCLUSION**

1. A method for recording precordial electrocardiogram (CB\textsubscript{1} or CB\textsubscript{2}) during exercise in performing Master's two-step test is described in detail. The electrocardiograms were recorded in four periods: (a) resting, (b) exercise, (c) early recovery, and (d) late recovery.

2. The double two-step test was performed in 32 normal subjects and 54 patients with various cardiovascular diseases. The changes in the electrocardiogram during and after exercise are reported and discussed.

3. The criteria for an abnormal response in the modified double two-step test are defined.

4. The significance of an increase in the amplitude of the T wave during exercise is clearly shown.

5. The modified method retains the merits of Master's original test and has several distinct advantages: (a) Changes in heart rate and the Q-T interval are recorded during exercise. The heart rate and the Q-T/T-Q ratio recorded during exercise may serve as a useful index of myocardial function. (b) It demonstrates that the electrocardiographic abnormalities in most cases of coronary insufficiency actually develop during exercise and persist to the recovery period. (c) In certain instances diagnostic changes are present only in the electrocardiograms taken during exercise, thus the sensitivity of the two-step test is augmented. (d) Since it makes possible electrocardiographic observation during exercise as well as during recovery it enhances the safety of the exercise test.

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