The Electrocardiogram during Exercise

Its Value in the Diagnosis of Angina Pectoris

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The diagnosis of angina pectoris, although fairly simple in the characteristic case, may not be made with certainty under a variety of conditions. In approximately 50 per cent of cases the diagnosis is made chiefly from the history, since objective evidence of myocardial abnormality may be lacking in the early stage. In the absence of a characteristic history, the difficulty in diagnosis may arise from atypical location of pain and simulation or association of angina with functional or extracardiac conditions.

To make a definite diagnosis, we often need all the aids at our disposal. The purpose of this communication is to discuss critically the value of the electrocardiogram in diagnosis and particularly to evaluate the information obtained during as well as after exercise.

We have performed exercise tests both during and after exercise in nearly 4,500 normal subjects and patients with various cardiac abnormalities in the past 4 years (table 1). Many improvements in the recording techinics have been made during this period, e.g., in the type of electrodes, electrode placement, the transmitter, and the receiving apparatus. Variations in results have been reported because of differences in apparatus employed, in electrode placement, and in the criteria of positive findings.

Table 1

<table>
<thead>
<tr>
<th>Cases Studied</th>
<th></th>
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<tbody>
<tr>
<td>Normal subjects</td>
<td></td>
</tr>
<tr>
<td>Ages 17 to 25</td>
<td>500</td>
</tr>
<tr>
<td>Ages 41 to 70</td>
<td>3,234</td>
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<tr>
<td>Total</td>
<td>3,734</td>
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<tr>
<td>Patients</td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>218</td>
</tr>
<tr>
<td>Angina pectoris</td>
<td>430</td>
</tr>
<tr>
<td>Myocardial infarction (healed)</td>
<td>66</td>
</tr>
<tr>
<td>Total</td>
<td>4,448</td>
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</table>

Apparatus and Techinics

The use of patch electrodes has been extremely helpful in obtaining satisfactory tracings.1–6 One may use the standard electrocardiograph with wire connections if the patient is located close to the recording apparatus.7 In our experience, however, varying degrees of interference are observed and the baseline is not as steady as with the telemetering apparatus. The Radio-electrocardiograph employed by us (RKG 100)* has been continually improved during the past 4 years.1–5 It has the usual standardization of 1 millivolt per centimeter.† It seems to be superior to similar types of apparatus and has worked very well for us as well as for others.8 The results compare favorably with

*Product of Telemedics, Southampton, Pennsylvania.
†The Sanborn specifications state that the response of the Viso 100 recorder is from 0.1 to 80 cycles per sec. The response of the RKG 100 is from 0.15 to about 1,000 cycles per sec. At various degrees of sensitivity, the curve of the Sanborn electrocardiogram alone and the combined Sanborn plus the RKG system were almost identical.
those obtained by the usual electrocardiogram under similar conditions (fig. 1).

Originally, a single lead was employed (similar to CRo). In the past 2 years, we have been using three leads (II, V₄, and V₆), which may be recorded successively with the use of a selector switch, or simultaneously with a three-channel machine. Regardless of the technic used, the electrocardiogram is recorded continually during the period of exercise, immediately (2 to 10 sec.) after exercise, and at 1, 3, and 5 minutes following exercise.

The heart performs its maximum work during the period of exercise. In normal human subjects, with the performance of exercise equal to walking on the level at 1½ to 5 m.p.h., the cardiac output rises to a peak within 1 minute, remains relatively stable during the period of exercise, and returns to a steady resting state within 1 minute after exercise. In cardiac patients, the cardiac output fails to increase adequately in response to exercise; moreover, there is a delay in its return to the control level following cessation of exercise. Such a response was observed in patients with mitral stenosis, hypertensive patients with exertional dyspnea, and cardiac enlargement associated with various pathologic states.

These studies indicate that the heart is under maximal strain during exercise when the metabolic demands are higher than normal. It is of interest that electrocardiographic changes often appeared during the initial period of exercise and became less marked thereafter despite continued exercise (fig. 2). In patients with severe disease, the changes often did not regress, but continued after exercise.

Criteria for Positive Test

The criteria for a positive exercise test have undergone considerable change since 1942, when the Master two-step test was originally described. Unfortunately, no unanimity for the criteria of positive tests has been
reached. Master himself has changed the criteria from time to time.\textsuperscript{6, 15–20} The percentage of positive findings in patients with angina pectoris in the series of Master et al. ranges from 91 to 96 per cent.\textsuperscript{6, 15–20} Most observers, including ourselves, have been unable to obtain such a high percentage of positive tests. The criteria are crucial in determining the percentage of false-positive and negative tests. The best choice would be to include the greatest number of distinctly positive cases with the exclusion of the greatest number of “truly negative” cases. Although many borderline cases may be then listed as negative, the number of “false-positives” would decrease.

There is apparent agreement on the presence of an ischemic ST-segment depression as an index of positivity. Many accept the figure of 0.50 mm. as abnormal, but others\textsuperscript{21, 22} are of the opinion that higher values of 0.75 mm. to 1 mm. should be the criteria of positivity. In this last group\textsuperscript{21–29} a high percentage of “false-positive” tests was found when 0.5 mm. was used as the criterion of positivity.

\section*{J Depression}

The significance of J depression after exercise is at the present time somewhat controversial. It is generally thought that a depression up to 1 mm. may be normal, but that 1.5 mm. or more is often abnormal.\textsuperscript{15, 30–36} In a recent report 70 per cent of patients with J depression of 2 mm. or more had ischemic heart disease, whereas this was true for only 40 per cent of those with 0.5-mm. J depression.\textsuperscript{37} Master et al.\textsuperscript{6} found a J-type depression of 0.5 mm. or more in 281 (60 per cent) of 468 unselected patients who manifested RS-T depression after exercise. Of these 92 (32.7 per cent) were diagnosed as having ischemic heart disease, whereas 189 (67.3 per cent) belonged to a “functional group.” We have frequently observed a J depression up to 1.5 mm. in normal subjects.\textsuperscript{5} On the other hand, depression of 2 mm. or more during and after exercise was frequently associated with ischemic heart disease or ischemic ST changes in other leads. A J depression of 2

\section*{QX/QT Ratio and QTr}

Recently, Master and Rosenfeld stated “The ratio of the actual measured QT to the ‘ideal’ or normal QT for the same heart rate, if 1.08 or greater after exercise, in our experience constitutes an abnormal response. A QT ratio of 1.07 or less is within normal limits.”\textsuperscript{18} This appears to be a relatively narrow range between the normal and the abnormal.

We, as well as others, have found the QX/QT ratio and QTr to be unreliable criteria.\textsuperscript{28} We found 22 per cent of 150 young, normal subjects that meet the positive or equivocal criteria.\textsuperscript{38} Friedberg et al.\textsuperscript{24} found “false-positive” or equivocal results in 32 per cent of noncardiac patients. Robb and co-workers\textsuperscript{39} concluded that the QX/QT and QTr are unreliable for evaluating the electrocardiogram after exercise. The QT interval is not easy to determine\textsuperscript{40–43}; although the beginning of QRS is clearly defined, it is difficult to determine the end of the T wave in many tracings; this is particularly true when the heart rate is rapid. Moreover, with exercise, U waves appear following or are superimposed on the end of the T wave and tend to obscure it. The Bazett formula\textsuperscript{44} for the determination of the normal QT interval works fairly well at heart rates within the normal range (70 to 90 per minute), but these tables are not reliable when the heart rate is over 100 per minute. Furthermore, exercise is nearly always accompanied by hyperventilation, which may produce considerable T-wave changes, QT prolongation, and ST-segment depression even in normal subjects. These changes add to the difficulty in determining the significance of slight grades of ST-segment depression and QT-segment prolongation.\textsuperscript{45}

\section*{Discussion}

The value of the electrocardiogram after exercise has been documented by numerous reports.\textsuperscript{6, 8, 15–20, 24–26, 28, 31, 37, 39, 46–49} The contribution of the electrocardiogram taken during exercise is great, but its exact role appears to require some elucidation.\textsuperscript{14–17, 19, 20}
Radioelectrocardiogram of a 46-year-old Negro woman with angina pectoris (lead V<sub>5</sub>). The control was normal. After 20 sec. of exercise, there was inversion of the T wave and slight ST-
ELECTROCARDIOGRAM DURING EXERCISE

Figure 3
Radioelectrocardiogram (V₅) of a white woman, age 60, with a clinically normal heart. Note the presence of occasional premature beats at 138 sec. of exercise. This eventuates a paroxysm of supraventricular tachycardia at 156 sec. Note the presence of only one atrial premature beat immediately after exercise and the absence of ectopic beats thereafter. This subject was not aware of any symptoms during the tachycardia.

The telemetered two-step test can be performed almost as quickly as the standard Master two-step test and involves no added risk to the patient.* Tracings taken during exercise often show abnormal changes, including ectopic beats, which are not recorded in the tracing after exercise and thus significantly increase the positivity of the exercise test (fig. 3). When positive findings appear, the exercise may be stopped immediately, even if pain is not experienced (fig. 4). The tracing immediately following cessations of exercise (2 to 10 sec.) is not recorded with the usual technic.

Few adequate comparative studies have been made between the tracings taken during and after exercise with similar technics, adequate apparatus, recording of similar specific leads, identical electrode placement, and criteria of positivity.

In our last 75 anginal cases with positive exercise tests, nine were positive only during exercise. Although positive findings were obtained both during and after exercise, they were more marked during exercise in 25 cases (fig. 5); the tracings were equally positive during and after exercise in 26, more after than during exercise in 12, and only after exercise in three cases. The test was terminated early in 16 because of both chest pain and electrocardiographic changes alone.⁵

The superiority of the electrocardiogram after exercise over the electrocardiogram during exercise has been claimed in a recent communication,⁶ with the comment that

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*An additional 5 minutes are required for preparation of the patient.

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segment depression; the ischemic ST-segment depression became more marked from 80 to 140 sec. One to 3 minutes after exercise, the ST-segment depression ranged from the ischemic to the J type; the changes after exercise were considerably less marked than during exercise.

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combined use of recordings during and after exercise does not "significantly alter the diagnostic yield." We disagree with these conclusions because of the following: Only one lead was used, whereas since 1962 we have been using three leads during the period of exercise as well as in the period after exercise. Master and Rosenfeld observed 80 per cent positives during the period of exercise and 91 per cent positives after the period of exercise. Since only one lead was used, the evidence is weighted considerably in favor of the postexercise data, where multiple leads were employed. Since the use of two additional leads (II and V1) adds 20 per cent to the incidence of positive findings, the percentage of positivities would naturally be increased. On the other hand, in our laboratory the combined positive yield obtained both during and after exercise was observed in only 74 per cent of the 35 patients with normal resting electrocardiograms. Actually, with the use of a single lead in the studies during exercise, the above-mentioned authors obtained a greater percentage of positive tests than we did with the

Figure 4

Master two-step test in a 72-year-old white woman (L.S.) with angina pectoris (lead V4). The test was stopped at 93 sec. because of chest pain and the development of a persistent left bundle-branch pattern. Note a single widened QRS at 9 sec. From 30 sec. on bundle-branch-block patterns became more frequent. At 72 sec. a continuous left bundle-branch block is present. Note the disappearance of this pattern immediately after exercise (within 2 to 10 sec.).
Figure 5

A white woman, age 54, with angina pectoris. Left-handed strips, lead II; right-hand strips, V4. Note (lead II) the ST-segment depression in the upright position. During exercise these changes become quite marked at 24 and 66 sec. They are still present immediately after exercise, and significant ST-segment changes are noted 1 minute, and to a lesser degree, 5 minutes after exercise. V4, on the other hand, shows an upright T wave in the supine and in the standing position. During exercise the T wave is inverted at 51 sec. and significant ischemic ST-segment depression are present at 93 sec. In the tracings after exercise, at 1 and 5 minutes inverted T waves are observed. The 1-minute tracing resembles that at 51 sec. of exercise; the 5-minute tracing does not show an ST depression. This figure shows that ST-segment depressions, when present, were observed during the period of exercise and were more marked during that period. It also illustrates that changes may be observed to different degrees in various leads.

combined use of three leads with records taken both during and after exercise. Much of the difference in results depends upon the type and strictness of the criteria employed in the two studies.

Does a Negative Exercise Test Exclude Ischemic Heart Disease?

The statement has recently been made that in the presence of a normal resting electrocardiogram a completely negative double two-step test practically excludes ischemic heart disease. We would challenge this statement because of the following considerations:

The incidence of positive tests in anginal patients reported in the literature ranges rather widely and depends upon many factors, such as the technic and criteria used. Russek obtained 61.3 per cent positive tests with ischemic ST-segment depression of 0.5 mm. as the only criterion; when Master's
other criteria were also imposed, the test was positive in 81.7 per cent, but the test was also positive in 19.4 per cent of the normal subjects. Lepeschkin and Surawicz, 26 using Master's criteria, found positive tests in 30 selected cases with a previous history of myocardial infarction or typical angina pectoris; but they observed 26 per cent false-positive tests in 243 noncoronary patients. Hellerstein et al., 46 depending upon the criteria used, observed abnormal responses ranging from 18 to 48 per cent of 92 consecutive patients with rheumatic heart disease and 100 consecutive patients with coronary artery disease. There was no significant difference in the incidence of abnormal electrocardiographic responses in rheumatic or arteriosclerotic heart disease. However, the incidence of abnormal responses varied according to the severity of disease as expressed by the functional and therapeutic classification, regardless of the cause. Friedberg et al., 24 using the criterion of an 0.5 ST-segment depression, observed 68 per cent positive and 12 per cent "false-negative" tests in anginal patients; but, 39 per cent of the nonanginal patients had "false-positive" tests. When 0.75 mm. or more was used as the criterion, the "false-positive" tests were reduced to 21 per cent, but the "false-negative" rose to 27 per cent. When a 1-mm.-segment depression was required for positivity, the "false-positive" tests diminished to 8 per cent in the nonanginal cases, but the "false-negative" tests rose to 43 per cent. In their patients with angina pectoris, Kimura et al. (1963) 47 observed 44 per cent positive tests. Master et al. (1942) 15 originally described an incidence of 67 per cent positive tests; but with revised criteria this group of investigators found the percentage of positivity to be 96.8 per cent (1957), 17 95 per cent (1961), 18 and 92 per cent (1964) 8 in their patients with angina pectoris.

In summary, therefore, the average incidence of a positive two-step test in the presence of coronary artery disease or angina pectoris, or both, as reported by numerous authors ranges widely and lies considerably below that obtained by Master et al. 6, 17, 18, 48

Most of the patients studied in the series mentioned above comprise well-documented cases of coronary disease (either postinfarction or anginal cases 6, 18, 20, 24, 26, 28), e.g., many of Master's cases have been followed for 8.2 to 9 years. 18, 20 However, the two-step test is most purposeful when the clinical findings, including the electrocardiogram, are relatively normal and the diagnosis of angina is in doubt. In such a prospective study coronary disease, if present, is more likely to be in an early stage, and the incidence of positive tests would not be expected to be as great as in the other groups cited by the various investigators. In other words, the standard of comparison employed comprises the electrocardiographic changes in subjects with well-documented and often advanced coronary artery disease; it is then applied to a group with early or incipient disease.

The tolerance to exercise and the electrocardiographic changes differ considerably in the same patient from time to time. Positive tests are not necessarily pathognomonic of ischemia; they may be due to other factors. 35

It is well known that chest pain or discomfort observed during the period of exercise may noticeably diminish or disappear as the exercise continues in some subjects. We have observed many cases in which evidence of ischemia occurred during the first 30 seconds of exercise, only to become less marked or disappear as the exercise continued. Similarly, MacAlpin et al. 49 observed that in six of 14 patients with angina pectoris, in which ST-segment depression and pain occurred early during exercise, there was subsequent diminution or disappearance of pain and the electrocardiographic abnormalities despite continued exercise. Mason et al. 50, 61 reported similar observations. Therefore, tracings after exercise may fail to record the most marked changes. The number of "false-negative" tests depends upon the group studied and the criteria used. Moreover, electrocardiograms taken even during painful episodes may fail to demonstrate ischemic changes. Most investigators evaluating the efficacy of the
exercise electrocardiogram have used the clinical history and follow-up data as criteria for differentiating between truly positive, "false-positive," and "negative" tests.

We think that the so-called "false-positive" test\textsuperscript{24, 26, 28} cannot always be lightly dismissed; for example, we have found 12 to 16 per cent positive tests in subjects in industry 40 to 60 years of age. A number of subjects develop significant abnormalities in the electrocardiogram with exercise and yet develop little or no symptoms coincident with these changes. Many may represent true positives. In a follow-up of 3 years, the incidence of coronary disease has been four times as frequent in those with positive tests as in a control group.\textsuperscript{52} Moreover, 52 per cent of 150 patients of a series by Francis et al.\textsuperscript{53} who developed myocardial infarction gave no previous history of angina. There is considerable documentation by retrospective studies that coronary disease of relatively severe grade may be present for many years without notable symptoms and that even myocardial infarction may occur in a large number of previously asymptomatic subjects.\textsuperscript{49, 54-56}

What is the Ideal Exercise Test?

Various types of exercise may be performed, e.g., stair climbing, the two-step test, walking on a treadmill, and the use of bicycle ergometer in the recumbent or upright position with various work loads. The first two methods are quite frequently used; however, not an ideal test for all subjects. Below the age of 40, a more strenuous exercise should probably be performed to elicit latent coronary disease. The comparison between the Master two-step test and the bicycle test suggests that the latter may be more diagnostic for the detection of latent coronary artery disease and the evaluation of the state of physical fitness in subjects below the age of 40 years. In this connection, one may also refer to the occurrence of negative tests with the Master two-step test in a subject with ischemic heart disease who is accustomed to performing moderate grades of strenuous exercise.

**Summary**

The electrocardiogram after exercise has proved to be an extremely valuable tool in the diagnosis of coronary artery disease. However, it fails to record the events during the actual period of exercise at the time of the greatest stress on the circulation. Recent technics have enabled us to take the electrocardiogram during the period of exercise. Data presented indicate that the electrocardiogram taken during this period of exercise adds much to the information obtained in the postexercise electrocardiogram; at times, this information may be crucial in determining evidence of abnormalities in the exercise study. The tracings may be solely positive or more markedly positive during the period of exercise. Evidence of such changes would be helpful in diagnosis and in the early termination of the exercise test. It is our belief that the complete electrocardiographic exercise study should include tracings taken both during and after exercise, and the data obtained during both of these periods should be available for evaluation.

Although the complete exercise test adds much to the diagnosis of coronary artery disease, the presence of a normal test does not necessarily exclude this state. Evaluation of the tracing taken during exercise is in its infancy. Much still needs to be done relative to (a) more adequate standardization of the type of exercise to suit the individual subject, (b) improvement of standardization of apparatus, (c) standardization of leads and their placement, and (d) more rigid standardization of criteria for normality and abnormality.

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