Radioelectrocardiography during Exercise in Patients with the Anginal Syndrome

Use of Multiple Leads

By Samuel Bellet, M.D., Otto F. Muller, M.D., Donald W. Lavun, M.D., George J. Nichols, M.D., and Allen B. Herring, M.D.

Previous studies from this laboratory on the alteration of radioelectrocardiographic recordings during and after the actual period of exercise were performed with a single electrocardiographic lead similar to CR₁ (one exploring electrode in the fifth intercostal space, left midaxillary line, and the second electrode over the distal end of the right clavicle). In a study of patients with angina pectoris with use of the single lead and the single Master two-step test findings were abnormal according to our criteria in only 53 per cent of 70 patients. By the addition of a lead selector switch interposed between the patient and the transmitter it is now possible to obtain any desired lead for telemetry. To standardize the recordings it was decided to use leads II, V₄, and V₆, changing these leads in 10-second intervals during the entire test.

In this study the electrocardiograms were re-evaluated in 90 patients with the anginal syndrome with use of the 3-lead system, and the incidence of positive and negative findings in patients with normal as well as abnormal resting electrocardiograms was determined.

Methods and Materials

A total of 90 patients (42 female, 48 male) with chest pain on exertion was referred from the Medical and Cardiac Clinics of the Philadelphia General Hospital. Their ages ranged from 33 to 84 years; 45 were over 60, 33 were between 50 and 59, and 12 were below 50. All patients had definite or suggestive clinical evidence of the anginal syndrome, manifested by a history of chest pain occurring with effort or after meals and relieved by sublingual nitroglycerin. In addition, 18 patients had a documented myocardial infarction in the past.

The technic of radioelectrocardiography, the principles involved, the apparatus, the types of electrodes used and their placement have been discussed in previous communications.

For the purpose of this study the specially designed Patch-type electrodes were firmly attached to the skin of all extremities at their junction with the torso and to the chest wall in positions V₄ and V₆.

Routinely, a standard 12-lead electrocardiogram was obtained with the conventional electrocardiograph on all patients at rest in the recumbent position. A control tracing consisting of leads II, V₄, and V₆ was then taken in the recumbent and erect positions with the radioelectrocardiograph. Standardized double two-step exercise tests were performed in a room with a constant temperature of 60 to 65°F. in the late morning before lunch. The radioelectrocardiogram was recorded continually from the time of the control tracing, during the entire exercise period, and for about 30 seconds thereafter. Leads II, V₄, and V₆ were taken successively for 10 seconds each during the period of exercise and immediately upon cessation of the exercise. Records were also taken at 1, 3, and 5 minutes after exercise.

The criteria for a positive test were those used in previous reports with slight modifications: (1) appearance or increase in ischemic ST-segment depression of 1 mm. or more, (2) junctional ST-depression of 2 mm. or more during exercise with straightening of the depressed ST after exercise, (3) T-wave inversion or the reversion of a

* RKG-100, manufactured by Telemedics, Inc., Southampton, Pennsylvania (a subsidiary of the Vector Manufacturing Company, Inc.).

From the Division of Cardiology, Philadelphia General Hospital, and Division of Cardiovascular Diseases, Graduate Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania.

Supported by grants from the National Institute of Health, HTS-5065, HE-07384-01 and Agreement 63-581-2, Heart Disease Control Program, Department of Health, Commonwealth of Pennsylvania.
negative T wave to an upright position, and (4) appearance of coupling or numerous premature ectopic beats.

The following changes were considered "probably abnormal": (1) ischemic ST-segment depression of 1 mm. or more in occasional cycles with slightly less depression elsewhere, (2) junctional ST-depression of 2 mm. or more during exercise only, and (3) marked changes in biphasic T waves either to positive or to negative.

**Results**

In 35 of the 90 cases the 12-lead control electrocardiogram was normal. Borderline abnormalities, e.g., flattened or biphasic T waves in some of the leads, slight ST depressions or elevations, and questionable left or right ventricular hypertrophy, were present in six cases. Tracings were abnormal in 49; 18 showed healed myocardial infarction; the remainder of the abnormal records revealed left ventricular hypertrophy (18 cases), nonspecific ST and T abnormalities (12 cases, excluding those with left ventricular hypertrophy), atrial fibrillation (two cases), and first-degree atrioventricular heart block (one case).

The results of the exercise tests are summarized in table 1. An abnormal or probably abnormal exercise test was obtained in 75 subjects (83 per cent) of the entire group, in 26 (74 per cent) of the 35 patients with normal resting electrocardiograms, in all six patients with borderline abnormal resting electrocardiograms, and in 43 (88 per cent) of 49 with abnormal resting electrocardiograms (table 1).

Table 2 lists the distribution of electrocardiographic alterations occurring during and after exercise in three groups of patients, those with normal, borderline abnormal, and abnormal resting electrocardiograms. The various types of electrocardiographic changes are shown in table 3, and the distribution of the alterations in different leads appears in table 4.

In 35 patients with electrocardiographic alterations during exercise the test was terminated early in 16 because of chest pain and electrocardiographic abnormalities and in 19 because of marked electrocardiographic changes alone (table 5).
Of the 15 patients without abnormal electrocardiographic changes during exercise the test had to be terminated early because of fatigue and shortness of breath in four, and in two because the patient complained of chest pain despite unchanged electrocardiographic records. Nine patients with definite clinical angina had, therefore, “false negative” tests (10 per cent).

Comparison of Double-Step Test with Previously Performed Single-Step Test

Twenty-nine patients who had performed single Master tests during our previous study were subjected to a standard double Master test. Of the 15 patients who previously performed a single test and presented negative findings 10 had positive findings during the double and one during the repeat single tests, whereas four patients failed to show abnormal changes during the double test. Four patients with previously “probably positive” single tests developed definite abnormal changes during the double test. Five of 10 patients with previously positive single tests again showed changes during the single test; the remaining five exhibited abnormal findings during the double test.

Discussion

Our experience has thusfar encompassed approximately 2,500 radioelectrocardiographic exercise tests; as a result we have been able more definitely to separate individuals with a normal response from those showing an abnormal response. Because of the results in healthy young subjects we have slightly modified the initial criteria reported in 1961.

It is our impression that J-segment depression of less than 2 mm. during the period of exercise may be a normal finding. J depressions of 2 mm. or more during exercise are associated with ischemic depression both during and after exercise so frequently that one may consider this finding abnormal (fig. 1). In some subjects an upright T wave in the recumbent position may invert upon standing; if this T wave becomes upright during exercise, the response may not be associated with abnormality. If an inverted T wave in the upright position becomes more markedly inverted or ST-segment depression occurs during or following exercise, the test is abnormal.

With the use of these criteria abnormal tests were obtained in 13 of 229 young “healthy” subjects (table 6).

On thorough clinical evaluation of the 13 subjects with abnormal tests latent diabetes was present in one patient, moderate hypertension in a second, and three complained of frequent although nonspecific chest pain. The incidence of positive tests in our patients with clinical angina pectoris was 76 per cent; an additional 8 per cent showed borderline abnormal exercise tests (table 1).

The incidence of positive tests in angina patients reported in the literature ranges rather widely and depends upon many factors, such as the technic and the criteria used. Master et al. observed an incidence of 67 per cent positive tests; Levan, 81 per cent; Grossman et al., 60 per cent; Robb et al., 69 per cent; Master et al., 96.8 per cent; to mention but a few.

Value of Recording Three Leads (II, V₄, and V₆)

Some areas rendered ischemic by the exercise may be manifested in certain lead positions and not in others. In our previous

Table 2

<table>
<thead>
<tr>
<th>Distribution of Electrocardiographic Alterations during and after Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal resting electrocardiogram</td>
</tr>
<tr>
<td>Borderline abnormal resting electrocardiogram</td>
</tr>
<tr>
<td>Abnormal resting electrocardiogram</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Circulation, Volume XXIX, March 1964
Table 3

<table>
<thead>
<tr>
<th>Types of Electrocardiographic Alterations Encountered during and after Exercise</th>
<th>Positive tests</th>
<th>T changes only</th>
<th>PVC only</th>
<th>ST and T changes</th>
<th>PVC and ST changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal resting electrocardiogram</td>
<td>26 (39%)</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Borderline abnormal electrocardiogram</td>
<td>6 (11%)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Abnormal resting electrocardiogram</td>
<td>43 (60%)</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>75 (79%)</td>
<td>7</td>
<td>17</td>
<td>34</td>
<td>14</td>
</tr>
</tbody>
</table>

* Indicates probably abnormal tests included in the total.
† Premature ventricular contraction.

Table 4

<table>
<thead>
<tr>
<th>Distribution of Electrocardiographic Alterations in Different Leads</th>
<th>Positive in single leads</th>
<th>Positive in combination of leads</th>
<th>Positive in combination of leads and PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total positive tests</td>
<td>25</td>
<td>6</td>
<td>42</td>
</tr>
<tr>
<td>Normal resting electrocardiogram</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Borderline abnormal electrocardiogram</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Abnormal resting electrocardiogram</td>
<td>18 (72%)</td>
<td>5 (83%)</td>
<td>5 (83%)</td>
</tr>
<tr>
<td>Total</td>
<td>24 (96%)</td>
<td>8 (100%)</td>
<td>8 (100%)</td>
</tr>
</tbody>
</table>

Circulation, Volume XXIX, March 1964
Table 5

Exercise Test Prematurely Terminated Because of Precordial Pain or Electrocardiographic Changes

<table>
<thead>
<tr>
<th></th>
<th>Total number of tests</th>
<th>Test terminated before completion</th>
<th>Developed pain after stopping exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal resting electrocardiogram</td>
<td>25</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Borderline abnormal resting electrocardiogram</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Abnormal resting electrocardiogram</td>
<td>42</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

studies the equivalent of CRn was the only lead recorded, but in the present investigations recordings from three leads (II, V4, and V6) were obtained. Of the 73 cases with abnormal or probably abnormal tests, 16 showed changes only in leads II or V4 or both. The use of these additional leads increased the incidence of positive findings by 21 per cent (table 4).

Positive Findings during Exercise and in the Immediate Post-Exercise Period

The distribution of positive findings during and after exercise in our present study indicates that tracings taken during the period of exercise are informative and add much to the entire electrocardiographic picture of a patient with coronary disease. In a certain percentage of cases (table 2) abnormal findings occurred only during the period of exercise and in a considerable number the findings were much more pronounced during this period (fig. 2). Two of our 26 patients with normal resting electrocardiograms and seven of 49 with abnormal resting electrocardiograms showed significant changes only during the period of exercise, and the alterations were much more pronounced during exercise in 10 of the first and in 15 of the second group.

Electrocardiographic alterations often appear during the first 10 seconds of exercise and are usually maintained during the period of exercise (fig. 3). Occasionally, they may recede again during exercise. In the records taken immediately (that is, 2 to 10 seconds) after the cessation of the exercise significant changes often appear; this period is not recorded with the usual type of the Master two-step test. One would expect that the electrocardiographic alterations would parallel the increase in metabolic demands that occur during the actual period of exercise. It has been shown by Donald and others that the load on the heart in normal subjects increases in the first minute of exercise at a steady pace, is maintained at a plateau during the period of exercise, and returns to normal within 1 minute after exercise. The return to normal may be delayed to 3 minutes or sometimes longer, however, in patients with myocardial abnormalities.

It is not difficult to explain the changes during the actual period of exercise and in the immediate post-exercise period, since the alterations in the metabolic processes occur with the beginning of exercise. Somewhat more difficult is the explanation why in some, even apparently healthy subjects, changes are more marked after exercise.

"False Negative" and "False Positive" Tests

It is not unusual to find subjects with well-documented angina pectoris due to coronary disease who show a negative electrocardiogram during the routine Master two-step test. In this series with the technic described above the incidence was 10 per cent.

On the other hand, ischemic ST-segment depressions and other significant changes are observed not uncommonly in apparently normal subjects above the age of 40. "False positive" tests occurred in 15 to 17 per cent of 300 presumably normal, actively working subjects studied outside of the hospital in industry. These subjects manifested no pain during the occurrence of these electrocardiographic changes.

In using the term "false-positive" one must
consider that the ST-segment depression and T-wave changes observed with exercise are not necessarily pathognomonic of coronary artery disease; these changes may be due to many factors other than ischemia. For example, overactive sympathetic tone, hyperventilation, poor physical conditioning, and digitalization may be etiologic factors. Electrocardiographic abnormalities are observed in a significant percentage of normal subjects after strenuous exercise and occasionally even just upon assumption of an upright posture. The

![Figure 1](http://circ.ahajournals.org/)

*Figure 1*

Exercise test in a patient with angina pectoris demonstrates association of very marked J-type ST depression during exercise (lead II) with ischemic depression (lead V₄) after exercise.
Table 6
Incidence of Positive Findings in Young “Healthy” Subjects

<table>
<thead>
<tr>
<th>Ages</th>
<th>Total no. of tests</th>
<th>Number of abnormal tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-25</td>
<td>124 (V₆ only)</td>
<td>5</td>
</tr>
<tr>
<td>20-39</td>
<td>105 (II, V₁, and V₆)</td>
<td>8</td>
</tr>
</tbody>
</table>

significance of these changes cannot be judged as a separate entity but must be considered and evaluated as part of the entire clinical picture. Positive tests are particularly apt to occur in the presence of various types of myocardial abnormalities, for example, in rheumatic and hypertensive heart disease and in patients suffering from extracardiac ailments.

Friedberg and associates²⁹ considered that the high percentage of false-positive and false-negative tests impaired the usefulness of the Master two-step test. With the use of an ST-depression of 1 mm. or more, their “false-negative” tests in 48 patients with angina

Figure 2
Electrocardiograms before exercise in recumbent and standing positions, during exercise at 40 and 100 seconds, and at various intervals after exercise. The control electrocardiogram is normal in the recumbent position. Note the increase in heart rate with slight decrease in the amplitude of the T wave and slight ST-segment depression in the standing position. Note the inversion of the T wave and ST-segment depression at 40 seconds and 100 seconds of exercise. A J-segment depression is observed in the tracing taken immediately (2 to 5 seconds) after exercise. The post-exercise electrocardiogram shows slight ST-segment depression of the J type. However, the most significant changes are observed during the period of exercise.
pectoris amounted to 43 per cent. This, indeed, appears to be a very high figure. In our series, after exclusion of those who did not complete the entire double Master two-step test because of pain or fatigue, the true incidence of "false-negative" tests in 84 patients was 10 per cent. If a patient is not cooperative in performing the exercise in the prescribed time or if he stops because of fatigue, apprehension, or other reasons, the study is invalid.

With reference to the group of 8 per cent false-positive tests of Friedberg et al., the following points may be made. There were only 38 patients in the nonanginal group, so that a change in a relatively small number of cases would significantly change the statistical data. It is difficult to evaluate the significance of these findings, since the age and specific diagnosis (normal, cardiovascular, extracardiac condition) were not mentioned. As stated above, "positive" tests are expected and might have implications other than ischemic heart disease. Furthermore, a positive exer-
cise test might signify early coronary artery disease in individuals who are symptom-free; this possibility may be decided after additional, long-term follow-up studies have been evaluated.

Summary

The electrocardiographic alterations during the period of and immediately following exercise were studied by means of radioelectrocardiography, in 90 patients with angina pectoris. Three leads (II, V4, and V6) were utilized.

The criteria for abnormality were based on the findings of 229 “normal” subjects between the ages of 17 and 39 and 300 “normal” subjects between the ages of 40 and 60.

Sixty-eight of the 90 patients (76 per cent) with angina pectoris showed electrocardiographic abnormalities during and after the period of exercise. An additional seven patients (8 per cent) manifested alterations that were considered to be “probably abnormal.” The incidence of false-negative tests was 10 per cent, those patients being excluded in whom the test had to be stopped early because of fatigue, leg pain, or other complaints.

The findings indicate that the recording of the electrocardiogram during exercise adds considerably to the value of the test. In some patients (12 per cent), the electrocardiogram was positive only during the period of exercise, and in 30 per cent the abnormal findings were obtained chiefly during this period.

The Master two-step test involves various technical and subjective difficulties such as interpretation of the alterations, wandering of the baseline, and lack of cooperation from the patient. In a certain percentage of patients with clinical angina pectoris false-negative tests are obtained. Also positive tests in subjects without definite anginal symptoms are not rare, but not enough long-term follow-up studies have been performed to delineate the significance of these findings.

In spite of some limitations, the exercise electrocardiogram, especially that taken during as well as after exercise, is an important adjunct in the diagnosis of angina pectoris.

References


Circulation, Volume XXIX, March 1964

Caleb Hillier Parry

The laws which govern the human frame might, doubtless, be experimentally ascertained with nearly as much precision as those of mechanics and chemistry, were it not for the intervention of another part of the compound which we would scrutinize. This is Mind, nurtured in prejudice and error, and therefore selfish; incomunicative and inaccurate, yet proudly expectant; at once capricious, irresolute, obstinate, and vindictive; suspicious; offended by reasoning, and averse to truth, yet credulous, and servilely grateful for being duped; equally intolerant of present inconvenience, and prone to present gratification. Examples of the difficulties arising from this source, which I have experienced during a professional practice of nearly forty years, crowd so forcibly and in such numbers on my memory, that to enumerate only a small part of them, would be to write the severest satire on the follies and vices of mankind.—Preface. Collections from the Unpublished Medical Writings of the Late Caleb Hillier Parry, M.D.F.-R.S. Vol. I. London, Underwoods, Fleet-Street, 1825, p. 2.
Radioelectrocardiography during Exercise in Patients with the Anginal Syndrome
Use of Multiple Leads
SAMUEL BELLET, OTTO F. MULLER, DONALD W. LAVAN, GEORGE J. NICHOLS and ALLEN B. HERRING

_Circulation_. 1964;29:366-375
doi: 10.1161/01.CIR.29.3.366
_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1964 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/29/3/366