QUANTITATIVE EVALUATION OF THE ST-T PATTERN IN THE EXERCISE ELECTROCARDIOGRAM

MASAKATSU FUKUSHIMA, M.D.

The exercise electrocardiogram has been widely accepted to be a most reliable non-invasive means for the diagnosis and evaluation of coronary heart disease. Although the extent of the ST junction's depression has been commonly used as a criterion for myocardial ischemia, the configuration of the ST-T segment and its serial changes throughout an exercise test have also been shown to be of great value for the evaluation of the exercise electrocardiogram. Among the various responses of the ST segment to exercise, the horizontal or sagging shaped ST depression is regarded as the typical "ischemic change". On the other hand, the junctional type of ST depression is often observed even in healthy adults. Since the conventional visual evaluation of the ST-T pattern such as junctional, horizontal and sagging shape is qualitative, the evaluation of the exercise electrocardiogram could be greatly influenced by the individual observer's criteria. Furthermore, the serial changes in the ST-T pattern during exercise have not been sufficiently investigated. Thus, in order to analyze the ST-T pattern quantitatively, we have developed a new computerized method for evaluation of the exercise electrocardiogram.

In this study, a second order function which represents the configuration of the initial portion of the ST-T segment was obtained by the function fitting and its coefficients were analyzed as the indices for evaluation of the ST-T change. In contrast to parameters such as ST slope and ST integral which have been proposed for the quantitative analysis of the exercise electrocardiogram, the coefficients of the fitted function were revealed to directly represent the curvilinear pattern of the ST-T segment. In our study, the serial changes in the ST-T pattern throughout the exercise test were also analyzed using these parameters to investigate their ability for coronary heart disease.

MATERIALS

The electrocardiographic responses to exercise were studied for two distinct groups, group EA and group H. Group EA consisted of 28 patients with effort angina pectoris (age ranging 36 to 76 years, average 58.3 years). They all experienced typical precordial pain or oppressive feeling during exercise which was relieved quickly by rest or administration of nitroglycerine. Patients who were taking digitalis or other drugs which could influence the ST-T segment were excluded from this study. Patients with abnormal Q waves in left precordial leads and bundle branch block were also excluded. Group EA was further subdivided into two subgroups by age; subgroup EA1 consisting of 14 patients of 59 years of age and under, and subgroup EA2 consisting of 14 patients of 60 or more.

Group H consisted of 35 healthy adults who had no clinical abnormalities and no symptoms during submaximal exercise tests (age ranging 21 to 70 years, average 35.1 years). Group H divided into three subgroups by age. 14 subjects in subgroup H1 were 29 years old or younger, 13 subjects in H2 were 30 to 39 years and 8 subjects in H3 were 40 or older.

METHOD

Multistage submaximal exercise tests were carried out on a bicycle ergometer (Monak). Exercise was begun at a work load of 150 kpm/min and the load was increased by 150 kpm/min at

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Serial analysis

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three-minute intervals. Exercise was terminated immediately upon the appearance of chest pain, marked exhaustion, marked dyspnea, serious rhythm disturbances or excessive ST-T changes. Exercise was also terminated if the heart rate increased to 80 percent of his predicted maximal heart rate. The electrocardiogram was recorded by Sanei monitoring equipment 3015A and systolic blood pressure was measured by the kuff method. The electrocardiographic signals were recorded from a bipolar chest lead, $V_{SR} - V_S$ system, and converted from analog to digital form by a Hewlett-Packard 5610A A-D converter at the rate of 240 samples per second. Digitalized data from a 10-second-segment each minute during the exercise tests were stored in the memory bank of a computer NEAC 3200 model 30 and the following modifications were made.

After the smoothing by a moving averaged method and the correction of the base-line shift, all QRS complexes in the 10-second-segment, except those from premature beats, were accumulated and averaged to reduce the effect of the noise and beat-to-beat variations of the ST-T segment. Recognition of the QRS complexes was made by identifying the negative slope of each R wave and the selected intervals of the electrocardiographic data were accumulated in the corresponding address aligned with the fiducial point, the R wave's peak. The base-line voltage was defined as the mean voltage of three successive points 40 msec before the beginning of the each QRS complex. By these means the averaged waveforms of the ST-T segments were obtained before exercise, each minute during exercise and an additional 10 minutes after the cessation of exercise.

For the quantitative analysis of the ST-T pattern, the initial portion of the ST-T segment obtained by the computer averaging method mentioned above were extracted and fitted by a second order function as follows using a minimum square method,

\[ f(t) = at^2 + bt + c \]

where \( t \) represents a time scale in 10 msec measured from the point 0.06 sec after the R wave's peak and \( f(t) \) represents the deviation (\( \mu \)V) of the ST-T segment from the base-line at each corresponding time (Fig. 1). The initial portion of the ST-T segment to be fitted is from 0.06 sec to 0.14 sec after the R wave's peak. Coefficients \( a \), \( b \) and \( c \) were used as the parameters which represent the ST-T pattern, and their serial changes throughout the exercise tests were analyzed.

Coefficient \( a \) represents the pattern of the initial portion of the ST-T segment since the configuration of the fitted function is mainly determined by this coefficient. Coefficient \( a \) is a comprehensive parameter which represents the curvilinear pattern of the ST-T segment. Its value is positive in the junctional type of ST depression, close to 0 in the horizontal type and negative in the sagging type. Coefficient \( c \) is equivalent to the intersect with a vertical axis, representing the extent of the ST junction’s depression.

RESULTS

Multistage submaximal exercise tests were carried out on a bicycle ergometer. In 22 out of 28 patients in group EA, the exercise was interrupted due to the precordial pain or oppressive feeling. In the remaining 6 patients in group EA and all subjects in group H, the exercise was also stopped owing to the exhaustion of legs, marked exertional dyspnea or the attainment of the target heart rate.

Table I shows the mean values of heart rate, systolic blood pressure and double product

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<table>
<thead>
<tr>
<th>Group</th>
<th>Age (mean)</th>
<th>Before exercise</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Heart rate (min)</td>
<td>Systolic blood pressure (mmHg)</td>
<td>Double product (mmHg/min)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21 - 70</td>
<td>75.9 ± 10.2</td>
<td>117.8 ± 13.4</td>
<td>9160 ± 1750</td>
<td></td>
</tr>
<tr>
<td>Group H</td>
<td>Subgroup H1</td>
<td>— 29</td>
<td>74.9 ± 7.3</td>
<td>116.0 ± 14.5</td>
<td>9230 ± 1710</td>
</tr>
<tr>
<td></td>
<td>Subgroup H2</td>
<td>30 - 39</td>
<td>76.8 ± 13.0</td>
<td>118.8 ± 12.6</td>
<td>9120 ± 1840</td>
</tr>
<tr>
<td></td>
<td>Subgroup H3</td>
<td>40 -</td>
<td>76.0 ± 9.2</td>
<td>119.5 ± 12.0</td>
<td>9130 ± 1670</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (mean)</th>
<th>At the last minute of exercise</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Heart rate (min)</td>
<td>Systolic blood pressure (mmHg)</td>
<td>Double product (mmHg/min)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>36 - 76</td>
<td>68.1 ± 10.2</td>
<td>128.0 ± 20.3</td>
<td>8700 ± 2060</td>
<td></td>
</tr>
<tr>
<td>Group HA</td>
<td>Subgroup EA1</td>
<td>— 59</td>
<td>70.5 ± 11.0</td>
<td>127.2 ± 16.2</td>
<td>9060 ± 2310</td>
</tr>
<tr>
<td></td>
<td>Subgroup EA2</td>
<td>60 -</td>
<td>65.7 ± 8.8</td>
<td>128.9 ± 23.9</td>
<td>8320 ± 1670</td>
</tr>
</tbody>
</table>

(heart rate $\times$ systolic blood pressure) before and at the last minute of exercise in both groups. Significantly higher level of heart rate was obtained during exercise in group H than in group EA.

1. Changes in coefficient $c$

Coefficient $c$ which corresponds to the intercept of the fitted function with the vertical axis (0.06 sec after the R wave's peak), represents the extent of the ST junction's depression. Although the values of coefficient $c$ decreased during exercise in all subjects in both groups, greater decrease was observed in group EA (Fig. 2, 3). The minimum values of coefficient $c$ in individual cases were obtained at the last minute of exercise in almost all cases except four subjects who demonstrated the minimal value a few minutes after exercise. The mean values of coefficient $c$ before exercise ($c_{BE}$), at the last minute of exercise ($c_{LE}$) and three minutes after exercise ($c_{AE}$) in each group are shown in Table II. In group EA as a whole, the mean values of coefficient $c$ at these three study intervals ($-34 \mu V (c_{BE})$, $-213 \mu V (c_{LE})$ and $-118 \mu V (c_{AE})$) were significantly less than the respective values in group H ($71 \mu V (c_{BE})$, $-25 \mu V (c_{LE})$ and $-3 \mu V (c_{AE})$). In group H, subgroup H1 showed higher values than the remaining two subgroups, although differences between subgroups H1 and H2 were not significant. In group EA, differences between two subgroups were not significant.

2. Changes in coefficient $a$

Coefficient $a$ represents the pattern of the initial portion of the ST-T segment. In all subjects in group H, this coefficient increased gradually as the work load and heart rate increased, and after exercise, it decreased rather rapidly showing a close correlation with heart rate (Fig.

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4, 6). On the other hand, in 19 out of 28 patients in group EA coefficient $a$ failed to show a concordant increase with the heart rate and in 15 patients this coefficient decreased to be negative after exercise (Fig. 5, 6). Indeed, the correlation between the coefficient $a$ and heart rate throughout the exercise tests was high in group H (the mean correlation coefficient is 0.86), while in group EA these two parameters showed poor correlation ($r = 0.32$). This indicates that coefficient $a$ of one individual should be compared with that of another subjects only when the heart rate is on the same level. In our study, therefore, the coefficients $a$ before exercise ($a_{BE}$), at the time when heart rate was 110–120/min during exercise ($a_{120}$), and three minutes after exercise ($a_{AE}$) were used for the individual comparison (Table III, Fig. 7) excluding the patients in group EA whose heart rate did not increase above 110/ min during exercise. The mean values of $a_{BE}$, $a_{120}$ and $a_{AE}$ of group EA were significantly less than those of group H. In group H, mean values of coefficient $a$ were less in the higher aged sub-

groups.

3. Discrimination of the patients with effort angina pectoris by the combination of coefficients $a$ and $c$

A discriminant function which incorporates coefficients $a$ and $c$ was used for the electrocardiographic diagnosis of effort angina pectoris. Good discrimination between these two groups was obtained by using the discriminant function with 6 parameters ($c_{BE}$, $c_{LE}$, $c_{AE}$, $a_{BE}$, $a_{120}$ and $a_{AE}$) as follows,

$$D = 0.0178 \times c_{BE} + 0.0366 \times c_{LE} - 0.0411$$
$$\times c_{AE} - 0.833 \times a_{BE} + 0.928 \times a_{120}$$
$$+ 1.01 \times a_{AE} - 1.26$$

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### TABLE II  MEAN VALUES OF COEFFICIENT c AT THREE DIFFERENT PERIODS OF THE EXERCISE TEST (mean ± 1 SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Coefficient c (µV, mean ± 1 SD)</th>
<th>Before exercise</th>
<th>At the last minute of exercise</th>
<th>Three minutes after exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>71 ± 71</td>
<td>−25 ± 60</td>
<td>−3 ± 57</td>
</tr>
<tr>
<td>Group H</td>
<td></td>
<td>100 ± 66</td>
<td>−4 ± 35</td>
<td>28 ± 36</td>
</tr>
<tr>
<td>Subgroup H1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroup H2</td>
<td></td>
<td>76 ± 74</td>
<td>−21 ± 67</td>
<td>−11 ± 63</td>
</tr>
<tr>
<td>Subgroup H3</td>
<td></td>
<td>12 ± 27**</td>
<td>−68 ± 62**</td>
<td>−45 ± 42***</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>−34 ± 75***</td>
<td>−213 ± 129***</td>
<td>−118 ± 93***</td>
</tr>
<tr>
<td>Group EA</td>
<td></td>
<td>−23 ± 43</td>
<td>−173 ± 98**</td>
<td>−96 ± 64</td>
</tr>
<tr>
<td>Subgroup EA1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroup EA2</td>
<td></td>
<td>−45 ± 96</td>
<td>−252 ± 143</td>
<td>−141 ± 110</td>
</tr>
</tbody>
</table>

Group EA (total): significant differences from group H (total). *p < 0.05, **p < 0.01, ***p < 0.001
Subgroup EA1: significant differences from subgroup H3. ◼ p < 0.05, ◼ ◼ p < 0.01, ◼ ◼ ◼ p < 0.001
Subgroup H2 and H3: significant differences from subgroup H1. *p < 0.05, **p < 0.01, ***p < 0.001
Differences between subgroup EA1 and subgroup EA2 are not significant.

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**Fig. 4.** Serial changes in coefficient c throughout exercise tests in group H. Upper panel: subgroup H1, middle panel: subgroup H2, lower panel: subgroup H3.

**Fig. 5.** Serial changes in coefficient c throughout exercise tests in group EA. Upper panel: subgroup EA1, lower panel: subgroup EA2.

\[
D > 0: \text{a healthy subject} \\
D < 0: \text{a patient with effort angina pectoris}
\]

The misclassification rate was 0.069. On the other hand, if \( c_{LE} \) of less than −100 µV, which corresponds to the conventional criterion for myocardial ischemia, was applied in our cases, 11 false positive or false negative responses (0.175
### TABLE III  MEAN VALUES OF COEFFICIENT $a$ AT THREE DIFFERENT PERIODS OF THE EXERCISE TEST (mean ± 1 SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Before exercise</th>
<th>at the time when heart rate was 110–120/min during exercise</th>
<th>Three minutes after exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>$1.1 \pm 0.9$</td>
<td>$4.4 \pm 1.6$</td>
<td>$1.9 \pm 1.4$</td>
</tr>
<tr>
<td>Group $H$</td>
<td>$1.2 \pm 0.8$</td>
<td>$5.0 \pm 1.7$</td>
<td>$2.1 \pm 1.0$</td>
</tr>
<tr>
<td>Subgroup H1</td>
<td>$1.3 \pm 0.9$</td>
<td>$4.2 \pm 1.4$</td>
<td>$2.1 \pm 1.8$</td>
</tr>
<tr>
<td>Subgroup H2</td>
<td>$0.5 \pm 0.6$</td>
<td>$3.7 \pm 1.5$</td>
<td>$1.2 \pm 1.2$</td>
</tr>
<tr>
<td>Subgroup H3</td>
<td>$0.6 \pm 0.8^*$</td>
<td>$1.3 \pm 2.1^{***}$</td>
<td>$-0.3 \pm 1.9^{***}$</td>
</tr>
<tr>
<td>Group $EA$</td>
<td>$0.6 \pm 0.9$</td>
<td>$1.9 \pm 2.1^*$</td>
<td>$-0.4 \pm 2.4$</td>
</tr>
<tr>
<td>Subgroup $EA1$</td>
<td>$0.6 \pm 0.7$</td>
<td>$0.7 \pm 1.8$</td>
<td>$-0.2 \pm 1.2$</td>
</tr>
</tbody>
</table>

Group $EA$ (total): Significant differences from group $H$ (total). $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Subgroup $EA1$: Significant differences from subgroup $H3$. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Subgroup $H2$ and $H3$: Significant differences from subgroup $H1$. $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Differences between subgroup $EA1$ and subgroup $EA2$ are not significant.

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Fig. 6. Typical changes in coefficient $a$ in both groups. Upper panel: a 27 years old healthy adult, lower panel: a 57 years old patient with effort angina pectoris.

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**DISCUSSION**

The configuration of the ST-T segment, as well as the extent of the ST junction's depression, has been emphasized to be of great value in the evaluation of the exercise electrocardiogram. Brody et al. reported that in subjects with the "ischemic ST-T change" in the exercise electrocardiogram the incidence of overt coronary heart disease was six times greater than that in subjects with junctional type of ST depression. Mattingly et al. also found the mortality rate of subjects with the "ischemic ST-T change" to be eight times greater than that of subjects with the junctional type of ST depression. However, the evaluation of the ST-T pattern, such as the junctional, horizontal and sagging shaped ST depression, is qualitative and could be much influenced by the subjective criteria of individual observers. Therefore, for the accurate objective analysis of the electrocardiographic response to exercise, the quantitative evaluation of the ST-T pattern must be established.

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Fig. 7. Individual values of coefficient $a$ at three different periods of exercise test. Left panel: coefficient $a$ before exercise ($a_{BE}$), middle panel: coefficient $a$ at heart rate of 110–120 /min during exercise ($a_{120}$), right panel: coefficient $a$ 3 minutes after exercise ($a_{AE}$).

Fig. 8. Individual relationship between $a_{120}$ and $c_{LE}$. $a_{120}$ is plotted along the vertical line, and $c_{LE}$ is plotted along the horizontal line.

1. Function fitting method for the quantitative analysis of the ST-T pattern

Although some parameters such as QX/QT$^{10}$ QT ratio$^{11}$ and slope of the ST segment$^{12}$ have been proposed for the quantitative analysis of the ST-T changes, considerable interobserver variations were observed in the visual interpretation of identical records mainly due to the various noise, the base-line shift and the beat-to-beat variations of the ST-T wave forms$^{13}$. In recent years, to reduce the influences of these erroneous factors the computer averaging method has been employed in the interpretation of the exercise electrocardiogram since these factors are independent of the cardiac cycle$^{14-17}$ and some parameters such as ST slope$^{15-17}$ and ST integral$^{18,19}$ were reported to be useful for the diagnosis of coronary heart disease.

In our preliminary study, to analyze the ST-T pattern quantitatively and time-serially, the initial portion of the ST-T segment was fitted by the polynomial function;

$$f(t) = k_n t^n + k_{n-1} t^{n-1} + \ldots + k_2 t^2 + k_1 t + k_0$$
Fig. 9. Serial changes in the amplitude of the T wave's peak throughout exercise tests.

Fig. 10. Typical changes in the ST-T pattern during exercise in the case of a healthy adult (a), and in the case of a patient with effort angina pectoris (b).
and coefficients $k_n$, $k_{n-1}$ ... $k_2$, $k_1$, $k_0$ were used as parameters which represent the ST-T changes. Although the accuracy of the fitting improved as the order of the fitted function increased, a satisfactory fit was obtained even with a second order function. Therefore, coefficients $a$ and $c$ of the fitted second order function, $f(t) = at^2 + bt + c$, were used for the discrimination of the patients with coronary heart disease. Coefficient $a$ represents the curvilinear characteristics of the ST-T pattern, while ST slope corresponds to the straight-line fit of the ST-T segment. Coefficient $b$ relates to the axis of the fitted function but was not used in this study since the axis ($t = -b/2a$) did not change significantly except when $r$ was close to 0. Coefficient $c$ is equivalent to the intersect with the vertical axis. It corresponds to the extent of the ST junction's depression which has been commonly used as a criterion of myocardial ischemia.

Although the isoelectric TP segment might provide an appropriate reference voltage from which the ST segment’s shifts could be measured the PQ segment immediately before the QRS beginning is used as a reference line (base-line) in this methods; (1) the isoelectric TP segment may be often too short to be recognized, especially when heart rate increases during exercise and (2) the end of the T wave and the beginning of the P wave may be recognized erroneously because of the low frequency constitution of these two wave.

2. Serial changes in the ST-T pattern

In all subjects in group H, coefficient $a$ increased during exercise with the increase of the work load and heart rate. Since the amplitude of the T wave which would greatly influence the ST-T pattern showed no remarkable change throughout the exercise test in group H (Fig. 9), it was suggested that the changes in coefficient $a$ in healthy subjects depend mainly on the QT interval shortening with increased heart rate (Fig. 10). On the other hand, in 19 out of 28 patients in group EA coefficient $a$ did not increase even though the heart rate increased markedly, showing poor correlation between these two parameters. In addition to the QT interval shortening some other factors such as the ischemic ST-T change may influence the changes in coefficient $a$ in group EA (Fig. 10). Although the maximal depression of the ST-T segment was observed just before or immediately after the cessation of exercise, the ischemic ST-T patterns such as horizontal and sagging shape were often apparent three or four minutes after exercise rather than immediately. Also in this study, 15 out of 28 patients in group EA showed negative values of coefficient $a$ during this period but not immediately after exercise. This may be due to the steeping of the T wave's up-slope which would obscure the underlying ST depression during and immediately after exercise because of the QT interval shortening with increased heart rate. A few minutes after exercise, however, heart rate decreased and the QT interval prolonged, unmasking the underlying "ischemic ST-T changes".

3. Aging effect in the ST-T responses to exercise

The electrocardiographic responses to exercise could be influenced by aging since the atherosclerotic changes in the coronary arteries increase with advancing age. In this study, in order to examine the effect of aging, both group H and group EA were further divided into subgroups according to age. In group H, mean values of coefficients $a$ and $c$ were less in the higher aged subgroups (Table II, III). These results confirmed previous reports that the incidence of the ischemic ST-T changes with exercise increases with advancing age. It was also found that the incidence of overt coronary heart disease in the subjects without any ischemic symptoms but with the ischemic ST-T response to exercise is very high; Beard reported this incidence to be 60 percent in a 2.5-year follow-up study and Doyle reported it to be 85 percent in a 5-year follow-up study. Subgroup H3 and subgroup EA1 roughly included similar ages. Two subjects in subgroup H3, who showed small values both of $a_{120}$ and $c_{LE}$ ($c_{LE}$ is in Fig. 8), may have considerable degree of coronary atherosclerosis. Even though such pre-clinical patients might be involved in subgroup H3, a significant difference between subgroup H3 and subgroup EA1 were observed both in coefficients $a_{120}$ and $c_{LE}$.

4. Quantitative evaluation of the exercise electrocardiogram

In this study, the electrocardiogram was recorded from a bipolar chest lead ($V_{SR} - V_s$), the best choice for a single exercise lead. Although myocardial ischemia in some region may be overlooked by using this lead only, a good discrimination between group H and group EA was obtained. To quantitatively evaluate the ST-T changes with exercise, a discriminant function was applied using before, during and after exercise coefficient $a$ which mainly represents
the ST-T pattern and coefficient \( c \) which reflects the ST junction's depression. The discrimination between group H and group EA was found to be considerably better by using this discriminant function than by using only \( c_{LE} \) as a criterion. A good discrimination was obtained also by using the combination of only \( a_{120} \) and \( c_{LE} \). From these results, it was confirmed that the information about the ST-T pattern is indispensable for the evaluation of the exercise electrocardiogram. The function fitting method used in this study has proved to be useful for the quantitative analysis of the fine changes in the ST-T pattern. Further, this method made it possible to analyze the time-serial changes in the electrocardiographic responses to exercise such as the stress (the myocardial oxygen consumption) -strain (the ST-T changes) relationship of exercise and this analysis would greatly contribute to the pathophysiologic evaluation of patients with coronary heart disease and also in the programming of the protocol of exercise therapy.

**SUMMARY**

A new method for the quantitative analysis of the exercise electrocardiogram was developed for the diagnosis of coronary heart disease. In this method, a second order function, \( f(t) = at^2 + bt + c \), which represents the configuration of the initial portion of the ST-T segment was obtained by the function fitting method and its coefficients \( a \) (a parameter which represents the ST-T pattern) and \( c \) (a parameter which reflects the ST junction's depression) were used for the evaluation of the exercise electrocardiogram. Serial changes in the ST-T pattern throughout exercise tests were also investigated using this method in two distinct groups; a group of 35 healthy adults (group H) and a group of 28 patients with effort angina pectoris (group EA). Although the smaller coefficients \( a \) and \( c \) which were obtained during and after exercise tests in group EA may reflect the ischemic changes, substantially large overlaps in each of these parameters was observed between group H and group EA. However, the discrimination between these two groups was improved if the combination of coefficients \( a \) and \( c \) were applied. These results strongly suggest that the configuration of the ST-T pattern is indispensable for the evaluation of the exercise electrocardiogram and that the new quantitative method used in this study is useful in the objective analysis of the fine changes in the ST-T pattern.

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