Studies on Electrocardiogram during Exercise*

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The recent utilization of radiotelemetering technique in the medical field has made it possible to record electrocardiogram during performance of exercise. BELLET (1961) presented the results of Master's "two-step test" on normal subjects and patients by using radioelectrocardiography. KOBAYASHI and YAMAKAWA (1962), respectively, devised various kinds of lead systems necessary for recording electrocardiogram during exercise. Among the results obtained by BELLET, attention should be given to the fact that various positive findings were clearly shown in the radioelectrocardiogram during exercise even in the case of coronary insufficiency with negative results in the postexercise recordings.

In stead of the radioelectrocardiography, we employed long wired cable system and designed electrodes between patients and the recording device which made patients from physical restrictions and enable us to trace electrocardiogram during exercise continuously.

Method

(1) Leads and electrodes
Electrodes are made of rubber disk of 5 mm thick and 28 mm in diameter (Fig. 1.). On one side of the disk, there is a pitting, 25 mm in diameter, in which silver coated copper plate is fixed. Since there is a space between the skin and the copper plate in an electrode, electrode paste commonly used for electrocardiography is filled in it. This is so-called "fluid electrode", and paste is used for buffering the movement between the skin and copper plate in an electrode. These electrodes are fixed on the surface of the skin with adhesive tape.

Lead wire is connected with each disk. Five electrode-disks are lead into a thick cable, which is connected to the recording machine. This cable is hung from the ceiling in order not to burden the subjects during the exercise.

(2) Lead system
The electrodes are placed at various sites of body surface in order to record electrocardiogram with stable base line and to attain the similar patterns to those from $V_1$, $V_5$, or $V_6$ of the routine 12 leads. Among the bipolar lead system, Bellet's lead system and Yamakawa's E-M lead systems are excellent for our purposes.

On the other hand, little has been done by using the unipolar lead system. There is no difficulty in making it in our method. Two electrodes are placed symmetrically in the both subclavicular region, which are considered to be equivalent to the electrodes on the both arms (Fig. 2.). On the back, two electrodes are fixed at the height of XII vertebrae, 2 cm apart laterally from spine. This place is convenient for recording electrocardiogram during the exercise, because electrodes on lumbodorsal fascia can easily get rid of troubles caused by muscular movements. They are thought equivalent to the both legs. Central terminal is constructed by combining foregoing electrodes, altogether through 100

*This study was presented at the 29th Kanto-Koshinetsu regional meeting of the Japanese Circulation Society.
Fig. 1. Leads and electrodes

Fig. 2. Electrodes fixed on body surface

KΩ resistance, and unipolar electrode is fixed on C₁, C₂, . . . or C₆. The electrocardiogram obtained in this method is slightly different from limb leads of routine 12 leads, while patterns C₁₋₆ are almost similar in forms to those of V₁₋₆, respectively. Voltage difference measured between central terminal devised by us and Wilson's central terminal is within 0.01 mV. Skin resistance is measured in each case without seeing imbalance between each leads. They are ranged from 3 to 8 kilo-ohms.

3. Recording procedure

Routine 12 leads are taken at rest in supine position. Then, 12 leads records modified by us are taken at rest in supine and standing position. After the preliminary procedure mentioned above, one unipolar electrode is left at the position of C₆ for the following exercise. Single Master's test is then performed. Unipolar electrocardiogram (C₆) is recorded continuously during and immediately after the exercise. As soon as the exercise is over, subject returns to the resting supine position. Electrocardiogram is recorded at every minute after the exercise. The routine 12 leads are taken three minutes after the exercise.

4. Materials

Thirty-six males and twenty-four females, aged from sixteen to thirty-five, are selected as normal subjects. As the cases of coronary insufficiency, thirty males and ten females are tested. They are negative in single Master's "two-step" test (postexercise) at the time of this experiment. The coronary insufficiency defined here implies three groups, i.e. (1) those who have once been positive in single Master's test (postexercise), (2) those who have clearly recognized clinical symptoms and (3) those with myocardial infarction.

5. Interpretation of wave pattern

The extension line of PQ segment is defined as base line. When the level of ST segment is lowered over 0.05 mV from that is seen before the exercise, it is considered as ST depression. Junctional
ST depression is frequently seen because of tachycardia caused by the exercise. In such cases QX/QT is calculated. When QX/QT exceeds over 50 %, it is taken as ST depression. As the amplitude of T before the exercise is set at 100 %, variation of its height is expressed in percentage. When T is already inverted before the exercise, the ratio of change in depth is used for calculation. When T wave is inverted during the exercise, the degree of inversion is treated as negative value. Other values which are necessary in interpretation waves of the electrocardiogram are handled in the conventional way.

RESULTS

Observations of the electrocardiogram during the exercise are done in the following manner.

1. Heart rate.
2. ST depression.
3. Amplitude of T.
4. Arrhythmia and change in QRS complex.
5. Relationship between the findings of electrocardiogram during the exercise and symptoms.

Heart rate

In normal subjects, the heart rate is increased from 3% to 125% during the exercise. The average increase in heart rate in this group is +73.4%. Among the patients with coronary insufficiency, the increased heart rate during the exercise varies from 13% to 125%. The
average increase in this group is +71.7%. Since, however, F_s = 0.0264, F_o 98/1 (0.05) = 3.94, no significance is shown between the two groups even at 5% level.

Increased heart rate in compared between the ST depression group and the ST non-depression group. The former group showed average increase in heart rate of 73.2%, while the latter showed 66.6%. Here, F_s = 0.58, F_o 98/1 (0.05) = 3.94, therefore, there is no significance between the two groups at 5% level.

(2) ST depression (Fig. 3.)

Elevation of ST segment is not observed in our series of tests. During the exercise, ST depression is found in fourteen cases (35%) among the patients with coronary insufficiency and two cases (3.6%) in normal subjects. Table I shows two by two table which consists of these variables. Here, \( \chi^2 = 16.3 \) (Yates' modification), Pr(\( \chi^2 > 3.841 \)) = 5%, Pr(\( \chi^2 > 6.63 \)) = 1%. Therefore, there is a significance at 1% level. Table II shows graded ST depression.

(3) Amplitude of T

T wave generally decreases its amplitude in all cases except in one normal subject. Decrease in height of T wave is graded in five groups, \( H_1 \sim H_5 \). Number of cases of each group is shown in table III.

Seven cases of coronary insufficiency (17.5%) and two normal subject (3.3%) belong to the group \( H_5 \). Many of them show flat or diphasic T wave. Giving these variables to the two by two table (Table IV), \( \chi^2 = 4.26 \) (Yates' modification) and Pr(\( \chi^2 > 3.841 \)) = 5% are attained. Therefore, there is significance between normal subjects and cases of coronary insufficiency at 5% level. This fact implies that T decreases its amplitude under 24% which are found commonly in the patients with coronary insufficiency and very rarely found in normal subjects (Fig. 4.)

Twelve cases of coronary insufficiency (30%) and six normal subjects (10%) belong to the group \( H_1 \) & \( H_5 \). Giving these variables to the two by two table (Table V), \( \chi^2 = 7.92 \) and Pr(\( \chi^2 > 3.841 \)) = 0.05 are attained. Therefore, there is significance between the cases of coronary insufficiency and normal subjects at 5% level. This fact implies that T decreases its amplitude under 49% more commonly among the patients with coronary insufficiency than in normal subjects.

Twenty-three case of coronary insufficiency (57.5%) and twenty-six normal subjects (43.3%) belong to the group \( H_3 \), \( H_5 \) & \( H_5 \). Giving these variables to the two by two table (Table VI),
The cases of coronary insufficiency are conventionally divided into two groups for the purpose of knowing the relationship between the electrocardiogram during the exercise and symptoms at the time of this experiment. The group with symptoms is composed of those who have symptoms within six months and the group without symptoms is composed of those who have not symptoms within six months. For the criteria of interpretation of electrocardiogram during the exercise, Master's criteria is used conventionally (later discussed).

Eleven cases out of eighteen (61.6%) are
positive in the group with symptoms, while ten cases out of twenty-seven are positive in the group without symptoms. Here, $\chi^2 = 5.67$, $Pr(\chi^2 > 3.841) = 5\%$ and $Pr(\chi^2 > 6.635) = 1\%$. Therefore, there is significance between these two groups at 5\% level. In the cases of myocardial infarction, three cases out of nine show positive during the exercise. (Table VII).

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**DISCUSSION**

(1) Cable-connection for the recording of electrocardiogram during the exercise

The indispensable conditions which should be pointed out in the first place for the electrocardiogram during the exercise are how to obtain faithful recording with stable base line and the wave patterns similar to $V_4$, $V_5$ or $V_6$ of routine 12 leads. In order to satisfy these conditions, unipolar lead system with the fluid electrode devised by us is very useful. The electrocardiogram obtained in this method is so similar to routine 12 leads, especially in chest leads, that it is convenient to compare each other. It goes without saying that this method can not be applied to sports medicine and aerospace medicine. However, emphasize should be given to clinical application as one of the diagnostic methods of coronary insufficiency. This cable-connecting apparatus for obtaining the electrocardiogram during the exercise can easily get rid of intractable interference obstructions in radiotelemetering method. Thus, the method and the apparatus we devised will have more utility in clinical field.

(2) Electrocardiogram during exercise

As far as the increase of the heart rate is concerned, there is no difference between normal subjects and the cases of coronary insufficiency. Therefore, this is not worth while applying to differentiation of the two.

There is significant difference between the cases if coronary insufficiency and normal subjects when observation is performed on ST depression of over 0.05 mV. This result would be applied to the diagnosis of coronary insufficiency with negative Master's test (postexercise). Since tachycardia is very frequently found during exercise, QX/QT should be carefully calculated in order to rule out false positive, in which QX/QT is under 50\%.

Normal subjects are scarcely found when T decreases its amplitude below 24\%. When a line is drawn at 49\%, more cases of coronary insufficiency would still be found under the line. Therefore, in clinical application, coronary insufficiency should be taken into consideration when T decreases its amplitude below 49\% and the diagnosis should be made when T is below 24\% of control value.

Master's criteria which is commonly used only in postexercise electrocardiogram is considered to be applicable even in the electrocardiogram during the exercise. Among the patients with coronary insufficiency with negative Master's "two step test" (postexercise), positive findings are found during the exercise in 51.5\%. This fact implies that the electrocardiogram during the exercise has much the same diagnostic value as postexercise electrocardiogram commonly taken in making diagnosis of coronary insufficiency. The electrocardiogram during exercise can be used not only in diagnostic method, but in knowing effect of coronary vaso-dilator in such cases of coronary insufficiency that have already turned negative in Master's test (postexercise) by preliminary treatment.

**SUMMARY**

Faithful electrocardiogram with stable base line is obtained during the exercise (Master's single "two-step" test) without using radiotelemetering method but using cable connecting apparatus devised by us. Forty cases of coronary insufficiency and sixty normal subjects are tested here and the result obtained is that Master's criteria is applicable even in the electrocardiogram during the exercise. According to this method and criteria, positive findings are found in almost half number of patients with coronary insufficiency who are negative in postexercise electrocardiogram.
REFERENCES