Spatial T Wave Changes Produced by Exercise in Health and Disease

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Using the modified Frank's lead system from our laboratory, the 3 orthogonal radioelectrocardiograms were taken in the normal subjects, the patients with hypertension, myocardial infarction and sclerotic heart disease. The line connecting the termini of mean T vectors at control or one stage and at the other stage in exercise, is named an exercise vector. The exercise vector at 15 sec. (Ex.-15") was directed from the left and anteriorly to the right and posteriorly in normal subjects. In severe hypertension, the Ex.-15" was directed from right and anteriorly to the left and posteriorly. The Ex.-15" in myocardial infarction tended to have the direction opposite to the infarction vector, for example, from the right and posteriorly to the left and anteriorly in anteroseptal infarction, and from the right and anteriorly to the left and posteriorly in anterolateral infarction. These results indicate that the Ex.-15" tends to have the direction reducing the magnitude of normal and abnormal ventricular gradient, and diagnostically useful sign in determining the ischemic area of heart.

The recent development of the radioelectrocardiogram,1),2) had made it possible to provide electrocardiographic recordings during the actual period of exercise as well as the immediate postexercise period. This technique seems to be more valuable for the detection of coronary artery disease than the conventional exercise electrocardiogram.3)-5) Most previous studies of radioelectrocardiographic exercise test, however, were analyzed with a single lead, and there have been few studies on spatial analysis of the electrocardiogram during exercise. The modified Frank's lead system,6) which was developed from our laboratory, facilitates the recording of 3 orthogonal tracing during exercise, and this method may contribute to the more precise evaluation of the exercise electrocardiogram. The present study was undertaken mainly to analyze spatial changes in the T wave in ischemic heart disease and hypertension during exercise, and to evaluate the clinical significance, changes of T wave configuration and changes in the ventricular gradient after exercise were studied. Special attention was given to the changes in the form of the T wave

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and ventricular gradient 15 sec. after beginning exercise.

**Materials and Methods**

Eighty-five patients (53 male, 32 female) from the Second Department of Internal Medicine of the University of Tokyo Hospital were included in this study. The ages ranged from 19 to 72 years. They were divided into four groups.

1. Normal subjects: This group included 26 patients with no apparent heart disease and no hypertension (15 male, 11 female, 19–64 years). Electrocardiograms were within normal limits.

2. Patients with hypertension: This group consisted of 25 persons with blood pressure over 160/95 (13 male, 12 female, 31–69 years). They had no congestive heart failure and no marked arrhythmia. Some of them showed the flattening or inversion of T wave on the electrocardiogram.

3. Patients with myocardial infarction: This group consisted of 21 patients who had abnormal Q wave on the electrocardiogram and had clinical symptoms of myocardial infarction (19 male, 2 female, 53–70 years). Infarctions were classified according to modified Hecht's criteria. There were 2 patients with anteroseptal, 5 with anterolateral, 2 with large lateral, 4 with posteroinferior, 2 with posterolateral, and 3 with anteroposterior. One strictly posterior infarction was included.

4. Patients with sclerotic heart disease: This group consisted of 13 persons who showed ST, T abnormalities on electrocardiogram without evidence of myocardial infarction and hypertension (6 male, 7 female, 46–72 years).

The methods of radiotelemetry with 3 orthogonal leads have been discussed in detail in a previous paper. For the purpose of the spatial analysis of the exercise electrocardiogram, a modification of Frank's orthogonal lead system was devised to diminish interference in electrocardiographic records during exercise. The 3 orthogonal leads were recorded simultaneously. A control tracing was taken before exercise. Records were taken at 15 and 30 sec. intervals during the exercise period. After cessation of exercise, electrocardiograms were taken at 30 sec. intervals for 7 min. The horizontal mean T vector (T) was calculated from the measured T areas in the X and Z axes. When the termini of T at 15 sec. after beginning of exercise (T-15”) and T before exercise were connected, a straight line was obtained, which was called the Exercise Vector at 15 sec. (Ex.-15”). The exercise vector for each period of exercise was obtained by connecting the termini of T recorded during each of the exercise period.

**Results**

1. Normal subjects (Fig. 1 and 2): In 22 cases, the line connecting the terminus of the T of the control and the terminus of the T at 15 sec. after beginning exercise was directed to the right and posteriorly, that is, the Ex.-15” was directed from the left and anteriorly to the right and posteriorly. In the remaining 3 cases, the Ex.-15” was directed from the left and posteriorly to the right and anteriorly. The T returned to its original position during exercise or after the cessation of exercise in all cases. In 7 cases, the T was directed
more left and anteriorly after exercise than before exercise.

2. Patients with hypertension (Fig. 3 and 4): In 15 cases, the $\bar{T}$ before exercise was directed to the left and anteriorly (2-a group). In the remaining 10 cases, the $\bar{T}$ before exercise was directed to the right and anteriorly (2-b group). In the 12 cases of 2-a group, the $\text{Ex.-15''}$ was directed from the left and anteriorly to the right and posteriorly. The $\text{Ex.-30''}$ or -1' was back
Fig. 3. ECG tracings of 31-year-old male with hypertension before, during and after exercise.

to the left anterior position. In the 3 cases of the 2-a group, the Ex.-15" was directed from the original point to a point more to the left. Two patients had angina pectoris and the other patient was thought to have sclerosis as well as hypertension because of age (65 yrs.). Therefore, in those cases with only
hypertension and without other complication, in which the $T$ before exercise was directed to the left and anteriorly, the $\text{Ex.}-15''$ was directed to the left and anteriorly to the right and posteriorly. The $\text{Ex.}-15''$ of the 2-b group was whether directed from the right and anteriorly to the left and posteriorly, regardless of patients had angina pectoris or not. The $\text{Ex.}-30''$ or $-1'$ in this group was not definitely directed but tended to be directed to the left and anteriorly in the process of exercise.

3. The patients with myocardial infarction (Fig. 5, 6, 7 and 8): As shown in Fig. 5, the $T$ of the patient with anteroseptal infarction was directed to the right and anteriorly before exercise and $\text{Ex.}-15''$ was directed to the left and anteriorly. Exercise vectors were directed more to the left and anteriorly during the course of exercise. The $T$ before exercise of the patients with an-

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**Fig. 5.** ECG tracings of patients with myocardial infarction before and during exercise.

upper; 58-year-old male with anterolateral infarction.
middle; 50-year-old male with posterior inferior infarction.
lower; 62-year-old male with strictly posterior infarction.
terolateral infarction was directed to the right and anteriorly in 3 cases and to the left and anteriorly in 2 cases. The $\bar{E}_{x-15''}$ was directed to the left and anteriorly in 3 cases and to the left and posteriorly in 2 cases. The successive exercise vectors were directed to the left and anteriorly or posteriorly during the course of exercise. The $\bar{T}$ before exercise in patients with large lateral infarction was directed to the right and anteriorly in 1 case and to the left and posteriorly in the other. The $\bar{E}_{x-15''}$ was directed to the left in one and to the left and posteriorly in the other. The $\bar{T}$ before exercise in patients with posterior infarction was directed to the left and anteriorly in 5 cases and to the right and anteriorly in the remaining case. In the 5 cases, in which the control $\bar{T}$ was directed to the left and anteriorly, the $\bar{E}_{x-15''}$ was directed to the right and posteriorly in 3 cases, to the left and posteriorly in 1 case, and to the more left and anteriorly in 1 case. The $\bar{T}$ before exercise in patients with antero-posterior infarction was directed to the left and anteriorly in 2 cases and to the right and anteriorly in 1 case. The $\bar{E}_{x-15''}$ was directed to the right and anteriorly in the former 2 cases and directly posteriorly in the latter case. The $\bar{T}$ before exercise of patients with strictly posterior infarction was directed to the left and anteriorly and the $\bar{E}_{x-15''}$ was directed posteriorly.

4. The patients with arteriosclerotic heart disease: In 7 cases in which
the $\bar{T}$ before exercise was directed to the left and anteriorly, the $\text{Ex.-15''}$ was directed to the left and posteriorly in 4 and to the right posteriorly in 3. In 5 cases in which the $\bar{T}$ before exercise was directed to the right and anteriorly, the $\text{Ex.-15''}$ was directed to the right and posteriorly in 4 and to the left and posteriorly in one.

**Discussion**

To analyze the change in T wave form during exercise, and the changes in the spatial orientation of the $\bar{T}$, many complicated factors such as heart rate, hemodynamic effects and metabolic changes should be considered. Changes in QRS deflections during and after exercise were not significant in this study and degree of changes in the T wave may therefore be considered parallel to the changes in ventricular gradients. Therefore the $\text{Ex.}$ was used to indicate the change in the spatial ventricular gradient vector ($\bar{G}$) between two different periods of exercise. Generally, the $\bar{G}$ decreased in spatial magnitude in normal subjects when the heart rate was increased but the mechanism for this is not known. Increased sympathetic tone might be one of the exact factors. At 15 sec. after beginning exercise increased sympathetic tone does not have a great effect on the heart as later in exercise. Also from the hemodynamic stand-

![Fig. 9. The Ex.-15'' of normal subject.](image-url)
point, blood pressure is not significantly increased during these short periods. The changes of the $\mathbf{G}$ at 15 sec. after beginning exercise was therefore thought to be produced chiefly by the change in heart rate. The spatial T wave change was therefore analyzed during exercise, especially that of 15 sec. after beginning of exercise utilizing the modified Frank's lead system.

In normal subjects the $\mathbf{Ex.-15''}$ was directed from the left and anteriorly to the right and posteriorly or from the left and posteriorly to the right and anteriorly (Fig. 9), that is, the $\mathbf{Ex.-15''}$ moved in such a way that the $\mathbf{G}$ did not change direction but decreased in magnitude. In cases with mild hypertension, in which the T before exercise was directed to the left and anteriorly, the $\mathbf{Ex.-15''}$ was directed in the same direction as in normal subjects. These results suggest that T wave changes 15 sec. after the beginning of exercise in normal and mild hypertensive subjects was influenced chiefly by the change in heart rate.

The change in direction of the $\mathbf{Ex.-15''}$ in cases with myocardial infarction was thought to be noteworthy. As shown in Fig. 12, 13, 14 and 15, the $\mathbf{Ex.-15''}$ was directed to the left and anteriorly in anteroseptal and anterolateral infarction. The $\mathbf{Ex.-15''}$ of large lateral infarction moved directly to the left or to the left and posteriorly. The $\mathbf{Ex.-15''}$ in strictly posterior infarction was directed posteriorly. The $\mathbf{Ex.-15''}$ in postero-inferior infarction was directed to the right and posteriorly, the left and posteriorly or the left and anteriorly. These results suggest that the $\mathbf{Ex.-15''}$ was directed toward the ischemic area of the

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Fig. 10. The $\mathbf{Ex.-15''}$ of 2-a group of hypertension.  
Fig. 11. The $\mathbf{Ex.-15''}$ of 2-b group of hypertension.
heart. There was the possibility that not only the change of heart rate but also local factors in the myocardium in the area of the infarction influenced the $\bar{G}$ 15 sec. after the beginning of exercise. If the factor that decreased the magnitude of the $\bar{G}$ with increased heart rate had the same effects as the effects produced on the myocardium by myocardial infarction, the direction of the $\text{Ex.-15''}$ would be related to the location of myocardial infarction, and could be explained by a decrease in the local $G$,\textsuperscript{10,11} which may be closely related to the production of $\text{Ex.-15''}$. In cases with rather severe hypertension, in which the $\bar{T}$ before exercise was directed to the right and anteriorly, the $\text{Ex.-15''}$ was directed to the left and posteriorly, as shown in Fig. 11. This may be explained in the same way as the example just given. In cases with arteriosclerotic heart disease, the $\text{Ex.-15''}$ was directed to the right and posteriorly or to the left and posteriorly.

![Fig. 12. The $\text{Ex.-15''}$ of antero-septal and antero-posterior infarction.](image1)

![Fig. 13. The $\text{Ex.-15''}$ of antero-lateral, large lateral and postero-lateral infarction.](image2)

![Fig. 14. The $\text{Ex.-15''}$ of postero-inferior infarction.](image3)
As shown in Fig. 15 the local $\bar{G}$ probably influenced on the Ex.-15".

In the time course of exercise, $\bar{G}$ decreased further in its magnitude without change in direction and increased in magnitude after cessation of exercise in a majority of normal cases. There were, however, a few cases in which $\bar{G}$ increased in magnitude early during the course of exercise. In cases with mild hypertension, the increase of $\bar{G}$ occurred earlier during exercise than in normals, regardless of the degree of increase in heart rate. This fact suggested that some other factors influenced the change in $\bar{G}$. It is possible that hemodynamic changes such as increase in blood pressure occurred.

The results of our study would indicate that the Ex.-15" may be useful in the diagnosis of ischemic heart disease and the direction of the Ex.-15" may indicate the location of the ischemic area of the heart.

**Summary**

This study was undertaken to analyze the spatial change in T waves that occurred during exercise in patients with ischemic heart disease and hypertension, and to evaluate the clinical significance of these changes in terms of the ventricular gradient.

(1) The exercise vector at 15 sec. in normal and mild hypertensive patients did not change the direction, but decreased its magnitude. This fact is
as same as the ventricular gradient is decreased its magnitude and does not change its direction in changing heart rate in normal person. This suggested that the T wave change at 15 sec. was influenced mainly by a change in heart rate.

(2) The exercise vector at 15 sec. in cases with myocardial infarction, arteriosclerotic heart disease and severe hypertension was directed to the area with evidence of myocardial infarction and enlargement, which suggests that a local ventricular gradient vector influenced the T wave changes at 15 sec.

(3) The exercise vector 15 sec. after beginning exercise was thought to be diagnostically useful in determining ischemic areas of the heart.

References