Detection of Diseased Coronary Artery by Exercise ST-T Maps in Patients With Effort Angina Pectoris, Single-Vessel Disease, and Normal ST-T Wave on Electrocardiogram at Rest

Isao Kubota, MD, Kanji Hanashima, MD, Kozue Ikeda, MD, Kai Tsuiki, MD, and Shoji Yasui, MD

To examine the clinical significance of ST-T isopotential maps, 87-lead body surface mapping was performed after treadmill exercise in 21 patients with effort angina pectoris, single-vessel disease, and normal ST-T waves on the resting electrocardiogram. Single-vessel disease was found in the left anterior descending artery (LAD) (nine patients), in the right coronary artery (RCA) (seven patients), and in the left circumflex artery (LCx) (five patients). At 40 msec after the J point, the isopotential maps showed the site of the minimum to be in the left anterior chest in all patients. According to the changes in the position of the minimum from the ST segment to the T wave, postexercise maps were classified into four types. Type A maps (n=8) were characterized by the persistence of the minimum in the left anterior chest until its negativity decreased and until it became less negative than another minimum that subsequently appeared in a different position. Type B maps (n=6) were characterized by the gradual movement of the minimum toward the lower thoracic surface. Type C maps (n=5) were characterized by the gradual movement of the minimum to the left upper direction and then to the back. Type D maps (n=2) did not show any of the characteristics of A, B, or C. All patients with type A, type B, or type C maps had single-vessel disease of LAD, RCA, or LCx, respectively. Thus, exercise-induced changes of isopotential maps during ST-T period were greatly dependent on the obstructed coronary artery, and these results provide new information for diagnosing ischemic areas in exercise electrocardiography. (Circulation 1989;80:120–127)

Exercise-induced ST segment depression in patients with effort angina pectoris is generally believed to be a reflection of subendocardial ischemia. However, regardless of which coronary artery is diseased, such ST segment depression most often occurs in the left anterior chest leads. Thus, predicting the location of ischemic areas is thought to be difficult from the body surface distribution of ST segment depression. Recently, Ishikawa et al reported the usefulness of body surface T wave potential distribution at rest to identify the involved coronary artery. In the present study, we examined the clinical significance of isopotential maps obtained during the ST-T wave after exercise in patients with effort angina pectoris, single-vessel disease, and normal ST-T waves on the resting electrocardiogram (ECG). We found that changes in the position of the minimum from ST segment to T wave were greatly dependent on the obstructed coronary artery. The results of this study provide new information for diagnosing the location of ischemic areas in exercise electrocardiography.

Methods

Subjects

Of about 600 consecutive patients who underwent treadmill exercise testing with body surface mapping and coronary arteriography to assess coronary artery disease, 97 patients were initially selected according to the following criteria: 1) stable effort angina pectoris with ischemic ST segment depression 0.1 mV or more after treadmill exercise, 2) no history of previous myocardial infarction, 3) no history of spontaneous or exercise-induced
ST segment elevation, 4) no ECG evidence of myocardial infarction, intraventricular conduction disturbances, or preexcitation syndrome, 5) coronary artery narrowing 70% or more of luminal diameter in at least one of the three major arteries, and 6) no valvular, myocardial, or congenital heart disease. Of the 97 patients, 32 were selected because they had a narrowing of 70% or more in only one coronary artery. Of these 32 patients, 11 were excluded because their resting ECGs showed ST-T wave abnormalities such as ST segment depression or an inverted or flat T wave.

The final study population consisted of 21 patients (17 men and four women, 41–69 years old). Four patients had increased left ventricular voltage (SV1 + RV5 or RV6 > 3.5 mV), but no patient showed any other ECG abnormalities. Nine patients had single-vessel disease of the left anterior descending artery (LAD), seven had single-vessel disease of the right coronary artery (RCA), and five had single-vessel disease of the left circumflex artery (LCx).

The control group consisted of 20 normal volunteers (all men, aged 24–44 years). None had a history of cardiac disorders or systemic arterial hypertension, and all had normal physical and ECG findings. None of the normal subjects had undergone coronary arteriography. Informed consent was given by all subjects before the study.

**Body Surface Mapping and Treadmill Exercise Testing**

Graded treadmill exercise tests were performed according to the Bruce protocol. All medication was stopped at least 24 hours before testing. Eighty-seven-lead ECG mapping was performed by means of a previously described technique6,6 before and 1.5 minutes after exercise. We did not perform body surface mapping during exercise because of the difficulty of obtaining noiseless data. Body surface mapping was performed with the HPM-5100 system (Chunichi Denshi, Nagoya, Japan).7 Eighty-seven electrodes were placed along the nine columns (A to I) on the anterior chest and four columns (J to M) on the back. Lines A, E, and I were on the right midaxillary, midsternal, and left midaxillary lines, respectively. Lead points E6 and E4 were located on the level of the second and fifth intercostal spaces, respectively. The four leads in the upper portions of the midaxilla were not obtained by direct measurement of electrocardiographic signals but were constructed by interpolation.

**Data Analysis and Map Display Format**

The isopotential maps were constructed at 4-msec intervals from the 40 msec after the J point to the end of the T wave before and after exercise. The time instants of the J point and of the T wave offset were identified by visual analysis from edited Frank X, Y, and Z leads, which were recorded simultaneously with the 87-lead ECGs. The site of maximal ST segment depression after exercise was defined as the site of the minimum in the isopotential map at 40 msec after the J point.

In every map format (see Figure 1), the left part reflects the anterior chest, the right part reflects the back, and the dotted area represents the positive potential area. The increment of the isopotential line in every map is 0.1 mV. The time after the J point is shown on the left upper position and the waveform of lead G4 is displayed on the left middle position. The plus sign (+) indicates the site of the maximum, and the minus sign (−) indicates the site of the minimum. The less positive or less negative sites in maps having multiple maxima or minima are shown by smaller plus or minus signs, respectively. A closed circle in a map indicates the site of the minimum at 40 msec after the J point. An arrow between the closed circle and the minus sign shows the trajectory of the minimum from 40 msec after the J point.

**Results**

**Normal Subjects**

The maps from a representative subject (27-year-old man) are shown in Figure 1. In preexercise and postexercise maps, the upper, middle, and lower panels represent isopotential maps of the early, mid, and terminal phases of the T wave, respectively. All maps show bipolar potential distributions with positive values located over the precordium and negative values over the right upper anterior chest and upper back. In all healthy subjects, both preexercise and postexercise T maps consistently showed this pattern.

**Patients**

Table 1 shows the patient characteristics and map findings of both preexercise and postexercise conditions. In one patient (case 9), the isopotential maps during the ST-T wave at rest were different from those of the control subjects and were judged to be abnormal. This patient had a negative potential area with a minimum in the lower anterior chest in the middle phase of the T wave. This patient had single-vessel disease of the RCA.

Figure 2 shows the site of maximal ST segment depression after exercise in all patients. Regardless of which coronary artery is diseased, the location of the maximal ST segment depression was found in the limited region of the left anterior chest. In other words, the site of the minimum in the isopotential map at 40 msec after the J point existed in the left anterior chest in all patients. The similarity of the sites made diagnosis of the diseased coronary artery difficult. This finding is in accordance with that of previous studies.2,3

According to the changes in the position and the voltage of the minimum from the ST segment to the T wave, postexercise ST-T maps were classified into four types. Type A maps (n = 8) were characterized by the persistence of the minimum in the left anterior chest until its negativity decreased and
until it became less negative than another minimum that subsequently appeared in a different position. Type B maps \((n=6)\) were characterized by the gradual movement of the precordial minimum toward

![Pre-exercise maps](image1)

![Post-exercise maps](image2)

**FIGURE 1.** Maps from a 27-year-old normal subject. Upper, middle, and lower panels represent isopotential maps of the early, mid, and terminal phases of the T wave, respectively. See "Methods" for the map display format.

the lower thoracic surface. Type C maps \((n=5)\) were characterized by the gradual movement of the precordial minimum to the upper left direction and then to the back. Last, type D maps \((n=2)\) included maps that did not show type A, B, or C.

Representative maps of type A from a 64-year-old man (case 1) are shown in Figure 3. At 40 msec after the J point, the single minimum was located at lead G4. This precordial minimum continued to stay at the same site until it disappeared. At 112 msec, the voltage of this minimum became less negative than that of another minimum that subsequently appeared in the left upper back. The negative area around the precordial minimum extended into the positive area located on the presternal region and caused an indentation of negative potential area. This site of indentation became a "less positive area" afterward (188 and 240 msec). Type A maps were generally characterized by a persistence of the precordial minimum, which was initially observed at 40 msec after the J point, until its negativity decreased and until it became less negative than the subsequent minimum that appeared in a different position. Eight patients had postexercise ST-T maps of type A, and all had single-vessel disease of the LAD. The postexercise isopotential maps of the other seven patients having type A are shown in Figure 4. Only those maps at the time when the precordial minimum became less negative than the subsequent minimum are displayed. A closed circle indicates the site of the minimum at 40 msec after the J point. Until the time of the displayed map, the precordial minimum stayed at the same site or moved only to the neighboring electrode site in each patient.

### TABLE 1. Patient Characteristics and Map Findings of Preexercise and Postexercise

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (yr)</th>
<th>Gender (M/F)</th>
<th>Diseased artery</th>
<th>Preexercise abnormality</th>
<th>Postexercise map type</th>
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<tr>
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<td>LAD</td>
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<td>A</td>
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<td>LAD</td>
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M, male; F, female; LAD, left anterior descending artery; RCA, right coronary artery; LCx, left circumflex artery.
Representative maps of type B from a 68-year-old man (case 9) are shown in Figure 5. At 40 msec after the J point, the minimum was in the left anterior chest. This precordial minimum moved gradually toward the lower thoracic surface with the progression of repolarization (232, 252, and 276 msec), which was the characteristic of type B. Six patients showed postexercise maps of type B, and all of them had single-vessel disease of the RCA. The postexercise maps of the other five patients with type B are shown in Figure 6. An arrow between the closed circle and the minus sign shows the trajectory of the minimum from 40 msec after the J point. Once the minimum left the precordial region, it never returned to the precordial region again in all patients with type B maps.

Representative maps of type C from a 41-year-old man (case 15) are shown in Figure 7. At 40 msec after the J point, the minimum was located at lead G3. The site of the minimum was lead G4 at 100 msec, lead H4 at 120 msec, and lead L5 at 200 msec. The gradual movement of the minimum from the precordium to the left upper direction and then to the back was the characteristic of type C. Five patients showed postexercise ST-T maps of type C, and all had single-vessel disease of the LCx. The postexercise ST-T maps of the other four patients are shown in Figure 8. An arrow shows the trajectory of the minimum from 40 msec after the J point. Once the minimum left the precordial region, it never returned to that region again in all patients with type C maps.

The postexercise ST-T maps of two patients (cases 20 and 21) did not show types A, B, or C, and we classified these maps as type D. In patient 20, the minimum at 40 msec after the J point moved to the left lateral chest and stayed at the same site until it disappeared (Figure 9, upper panel). In patient 21, the minimum at 40 msec after the J point first moved inferiorly, then superiorly, and finally reached the left anterior chest (Figure 9, lower panel). This minimum stayed at this site until it disappeared. Both maps were different from any map of type A.
FIGURE 4. Postexercise isopotential maps of patients showing type A (except case 1, Figure 1). Only those maps at the time when the precordial minimum became less negative than the subsequent minimum are displayed. A closed circle indicates the site of the minimum at 40 msec after the J point.

B, or C. Patient 20 had single-vessel disease of the RCA, and patient 21 had single-vessel disease of the LAD.

Table 2 shows the relations between types of postexercise ST-T maps and diseased coronary arteries in the 21 patients studied. All patients with type A (n=8), type B (n=6), or type C (n=5) maps had single-vessel disease of LAD, RCA, or LCx.

Discussion

Normal Subjects

The isopotential map of the T wave in normal subjects at rest showed a consistent pattern of bipolar potential distributions with the positive values over the precordium and the negative values over the right upper anterior chest and the upper back. This pattern was the same as those described in previous reports. Exercise did not change this pattern significantly, suggesting that the sequence of ventricular repolarization was not greatly influenced by the exercise in normal subjects.

Rest Maps

Ishikawa et al reported that the T map abnormalities at rest were observed in 24 of 48 patients (50%) with angina pectoris and single-vessel disease and were classified into three types. Type 1 maps were characterized by a segmental negative potential in the positive area that was located on the left anterior chest. Type 2 maps were characterized by a negative potential area with a minimum in the inferior thorax and an indentation of negative potential at the lower margin of the positive potential located over the upper thorax. Type 3 maps were characterized by a negative potential with a minimum at the back throughout the period of T wave. Ishikawa et al found that all patients with type 1, type 2, or type 3 maps had single-vessel disease of LAD, RCA, or LCx, respectively. The T map abnormality at rest of our patient 9 corresponded to their type 2, and patient 9 had single-vessel disease of the RCA. In our study, however, an abnormal T map was observed only in one of our 21 patients (5%), a percentage much smaller than the 50% of their study. The difference in the frequency of the abnormal T maps is probably due to the selection of patients. We excluded patients with an abnormal ST-T wave on the ECG at rest because the purpose of our study was to investigate the clinical significance of exercise-induced changes in ST-T maps, whereas Ishikawa et al did not exclude such patients.

Exercise Maps

This study shows the usefulness of postexercise isopotential maps in diagnosing the stenosed coronary artery. In 19 patients with type A, B, or C
Detection of Diseased Artery by Exercise ST-T Maps

Figure 5. Postexercise isopotential maps from a 68-year-old patient with type B. The precordial minimum observed at 40 msec after the J point moved gradually toward the lower thoracic surface during the progression of repolarization. See "Methods" for the map display format.

Figure 6. Postexercise isopotential maps of patients showing type B (except case 9, Figure 5). A closed circle indicates the site of minimum at 40 msec after the J point. Arrow between the closed circle and the minus sign shows the trajectory of the minimum from 40 msec after the J point.

Figure 7. Postexercise isopotential maps from a 41-year-old patient with type C. The precordial minimum observed at 40 msec after the J point moved gradually to the left upper direction and then to the back from 100 to 200 msec. See "Methods" for the map display format.
maps, the changes of postexercise ST-T maps were dependent upon the obstructed coronary artery. All patients with type A (n=8), type B (n=6), or type C (n=5) maps had single-vessel disease of LAD, RCA, or LCx, respectively. Therefore, we were able to identify the diseased artery in 90% (19 of 21) of our study population.

Nakajima et al reported that the ST-T isointegral map after exercise was useful for diagnosing the ischemic region evaluated by exercise 201TI scintigraphy in 28 patients with effort angina. They concluded that the ischemic region was localized at anterior, inferoposterior, and lateral region of the left ventricle if the negative ST-T integral area was present in the anterior chest, inferoposterior chest, and left lateral chest, respectively. Although only 10 of their 28 patients had single-vessel disease, our findings also suggest that similar results can be inferred. However, as Nakajima et al pointed out, even when an ST-T isointegral map shows a normal pattern, significant ST segment depression often appears after exercise. Perhaps an ST-T isointegral map does not always provide sufficient information about body surface potential distributions during the ST-T period. Although the ST-T isointegral map may show the location of ischemia more clearly than does ST segment mapping alone, we think detailed examination by isopotential maps from the ST segment to the T wave are needed for more accurate detection of the site of myocardial ischemia.

**Underlying Mechanisms**

Experimental studies have reported that the sequence of repolarization is from the epicardium to the endocardium because the action potential duration of the endocardial region is longer than that of the epicardial region and because the difference is greater than the conduction time from the endocardium to the epicardium. This factor is considered to be the principal cause of the location of the positive potential area over the left anterior chest throughout the T period in normal subjects.

Postexercise ST-T maps of the patients showed various patterns. With the progression of depolarization, the minimum observed in ST segment period remained in the precordial region in type A, moved inferiorly in type B, and moved to left upper direction and then to the back in type C maps. The relation between the types of postexercise ST-T maps and diseased coronary arteries suggested that...
the electric changes occurring regionally in the anterior, inferior, or lateral walls of the left ventricle played a major role in producing type A, B, or C ST-T maps, respectively. So long as the ventricular activation sequence does not change, the most important factor that determines the configuration of the T wave is the spatial relation of action potential durations in the ventricles. The regional electric changes with the observed phenomena could be due to either regional prolongation of the action potential duration of the epicardial layer or regional shortening of the action potential duration of the endocardial layer. We think that the latter is a more plausible mechanism because exercise-induced myocardial ischemia occurs mainly in the subendocardium and ischemia has been reported to cause shortening of the action potential duration.11

Clinical Implications

Isopotential maps of the ST-T period after exercise were found to be useful in identifying the diseased coronary artery in our study population. Clearly, the present results cannot be applied to patients in general because the study group consisted of highly selected patients with a positive exercise test, single-vessel disease, and normal ST-T waves on the resting ECG. Further study will be required to clarify the significance of ST-T maps after exercise for the detection of the site of myocardial ischemia in patients having multivessel disease or ST-T abnormalities at rest.

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KEY WORDS • body surface mapping • isopotential mapping • heart disease • angina pectoris • exercise tests
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Circulation. 1989;80:120-127
doi: 10.1161/01.CIR.80.1.120

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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