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Isointegral Analysis of Body Surface Electrocardiographic Mapping for Assessing Exercise-Induced Changes in Repolarization Properties in Patients with Coronary Artery Disease

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To assess the exercise-induced changes in repolarization properties in patients with coronary artery disease, we analyzed body surface ECG mapping. The patients studied had a normal resting 12-lead ECG and were divided into 2 groups: group A (*n* = 15; coronary artery narrowing [–], exercise thallium defect [–], ST depression ≥ 0.1 mV [–]) and group B (*n* = 17; [+], [+], [+]). All patients in group B showed significant area (< –10 μV·s) in the postexercise ST-T isointegral map. Of the patients in group B, 10 (59%) showed significant area in the postexercise QRST isointegral map and 15 (88%) showed "–2SD area (less than mean –2SD values in group A)" in the difference map between resting and postexercise QRST isointegrals. The correlation coefficient between resting and postexercise QRST isointegrals in 87 lead points was significantly lower in group B (0.28 ± 0.56) than in group A (0.91 ± 0.06, *P* < 0.001). Our results indicate that patients with ischemic ST depression have a greater decrease in the QRST isointegral values in the precordial region than patients without ischemia and ST depression. There are also low similarities between resting and postexercise QRST isointegral maps. We conclude that ischemic ST depression is related to the dispersion of the exercise-induced changes in repolarization properties.

Key words: body surface ECG mapping; coronary artery disease; exercise test; QRST isointegral mapping

ST depression is used as a marker of myocadial ischemia in the exercise-stress ECG test for the detection of coronary artery disease. ST depression is commonly accompanied by a decrease in the height or inversion of the T wave. These ST-T changes are attributed to local repolarization abnormalities due to ischemia. Body surface QRST isointegral mapping has been used to assess repolarization properties in a variety of diseases (Montague et al., 1981; Kubota et al., 1984; Gardner et al., 1986; De Ambroggi et al., 1986; Hayashi et al., 1988, 1989; Tsunakawa et al., 1989; Hirai et al., 1991, 1993; Dambrink et al., 1995). However, there are few reports on the exercise-induced changes in the QRST isointegral in body surface ECG mapping in patients with coronary artery disease. In order to determine whether ischemic ST depression reflects the dispersion of the exercise-induced changes in repolarization properties or not, we quantitatively analyzed body surface QRST isointegral maps recorded at the same time when exercise-stress thallium-201 myocardial imaging test was performed for the detection of coronary artery disease.

Abbreviations: bpm, beats per minute; ECG, electrocardiography or electrocardiogram

Subjects and Methods

Subjects

We retrospectively studied 32 patients who underwent exercise-stress thallium-201 myocardial imaging and body surface ECG mapping for the detection of coronary artery disease. The patients we studied had a normal resting 12-lead ECG and were divided into 2 groups. Group A consisted of 15 patients (9 men and 6 women, mean age 60 years, range 44 to 75) who had atypical chest pain and had neither significant coronary artery narrowing nor exercise thallium defect nor significant exercise-induced ST change. Group B consisted of 17 patients (13 men and 4 women, mean age 68 years, range 57 to 80) who had significant exercise-induced ST depression, significant narrowing in at least one of major coronary arteries and reversible thallium defect. Excluded were patients with exercise-induced ST elevation, bundle branch block or atrial fibrillation, or any physical disability for undergoing an exercise tolerance test. No patients had congenital or valvular heart disease, hypertrophic or dilated cardiomyopathy, hypertensive heart disease or chronic obstructive lung disease. Vasodilators were not discontinued. No patients received antiarrhythmic drugs. Excluded were also those who showed no separation of T and P waves during body surface ECG mapping. Patient characteristics are shown in Table 1.

Table 1. Patient characteristics

	Coronary narrowing	Thallium imaging	12-Lead ECG
Group A [15]	< 50%	No defect	No ST depression
Group B [17]	≥ 75%	Reversible defect	Down-sloping, ST depression ≥ 0.1 mV

[ ], number of patients.

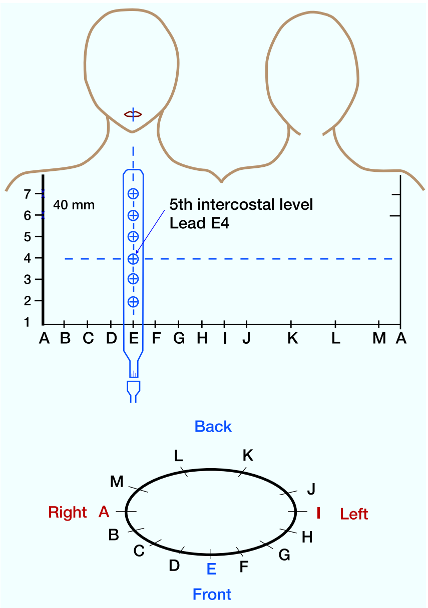

Fig. 1. Electrode placement for 87 lead points. The vertical distance between two lead points is 40 mm. E4 is located on the level of the fifth intercostal space. Leads G4, H4 and I4 correspond to V4, V5 and V6 of 12-lead ECG.

Informed consent was given by all patients for undergoing this exercise test.

Coronary arteriography and left ventriculography

All patients underwent coronary arteriography and left ventriculography within 1 month of this exercise test. Patients in group A had no coronary artery narrowing ≥ 50% and had normal left ventricular wall motion. Patients in group B had narrowing ≥ 75% in at least one of major coronary arteries. Those with akinesis, dyskinesis or aneurysm in any segment of the left ventricular wall were not included in group B.

Exercise-stress thallium-201 myocardial imaging

Supine bicycle exercise was begun at 25 W, and the work rate was increased by 25 W every 3 min. A dose of 111 MBq of thallium-201 was injected intravenously at peak exercise, and patients continued to exercise for an additional minute. A modified 12-lead ECG according to the Mason and Likar method (1966) was recorded at rest, every minute during exercise, and after 1, 2 and 3 min of recovery. Blood pressure was measured with an automatic sphygmomanometer (Nippon Colin, STBP-680, Tokyo, Japan) on the left arm. The end point of exercise was determined by the development of moderate anginal chest pain, severe shortness of breath or severe leg fatigue, new ST depression ≥ 0.2 mV at 80 ms from the J point in at least one lead except leads aVR, aVL and V1, or the achievement of 85% of age-adjusted predicted maximum heart rate. Significant ST depression was defined as new

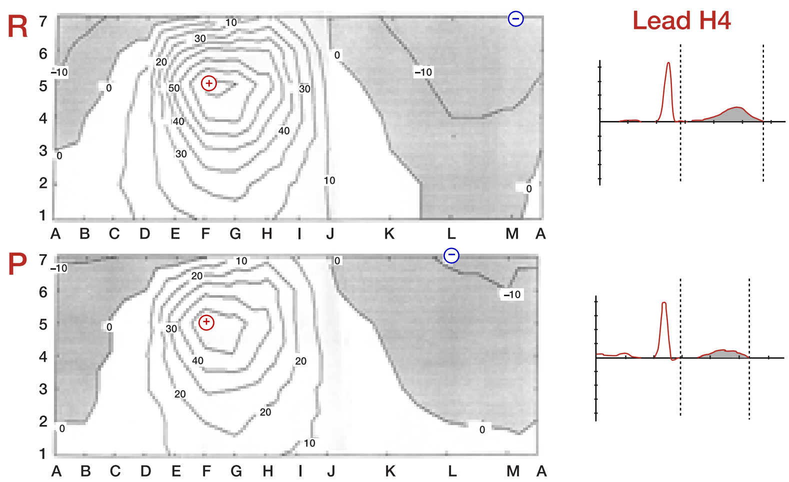

Fig. 2. Resting (**R**) (upper panel) and postexercise (**P**) (lower panel) ST-T isointegral maps of a patient in group A. Isointegral contours are separated by 10 μV·s. Shading indicates negative areas. Maximum and minimum are indicated by plus and minus signs.

down-sloping depression ≥ 0.1 mV at 1 min of recovery. Tomographic thallium-201 imaging was performed using a gamma camera (Hitachi, GAMMA-VIEW, Tokyo) equipped with a high-resolution, low-energy parallel-hole collimator and interfaced to a dedicated computer system (Hitachi, HARP). Initial imaging was begun 10 min after the termination of exercise and delayed imaging was repeated 4 h later. Thirty-two projections over a 180-degree arc were obtained with a 64 × 64 matrix. Short-axis, vertical long-axis and horizontal long-axis tomograms were reconstructed. The left ventricle was divided into the anterior wall (anterior and apical segments) and the posterior wall (inferoposterior and posterolateral segments). Images were interpreted by three observers. A defect was classified as reversible (partial or complete redistribution) or irreversible (no redistribution or equivocal). A consensus of the opinions of the three observers was taken. A reversible defect was used as a positive criterion for myocardial ischemia.

Body surface ECG mapping

Body surface ECG maps were recorded using a VCM-3000 system (Chunichi Denshi, Nagoya, Japan) at the resting expiratory level before and 1.5 min after exercise. Unipolar ECGs were recorded simultaneously from 87 lead points on the chest and back (59 and 28 leads, respectively) with reference to Wilson's central terminal (Fig. 1). The Frank X, Y, Z ECGs were also recorded simultaneously. The PR-segment was used as a baseline. The onset of QRS, the J point and the offset of the T-wave were determined from the spatial magnitude. The ST-T and QRST isointegrals were calculated for each lead as the algebraic sum of potentials from the J point or QRS onset to the T-wave offset and expressed in μV·s. Resting and postexercise ST-T isointegral maps, resting and postexercise QRST isointegral maps and the difference map between resting and postexercise QRST isointegrals were constructed. The ST-T and QRST isointegral contours were separated by 10 μV·s. A previous study of normal adults showed that the normal QRST isointegral map pattern has a dipolar character with two extremes: one positive (maximum) and one negative (minimum) (Montague et al., 1981). A QRST isointegral extreme was defined as a circumscribed peak in the smooth and graduated potential distribution. The map pattern was defined as nondipolar if three or more extremes were present. An additional extreme was considered present if an area of equal polarity included at least 2 lead points (Dambrink et al., 1995). Body surface was divided vertically into right (columns A to D, L and M) and left (columns E to K) regions, and divided horizontally into inferior (lines 1 and 2), mid (lines 3 and 4) and superior (lines 5 to 7) regions. Significant area in the postexercise ST-T or QRST isointegral map was defined as a new negative area including at least 3 lead

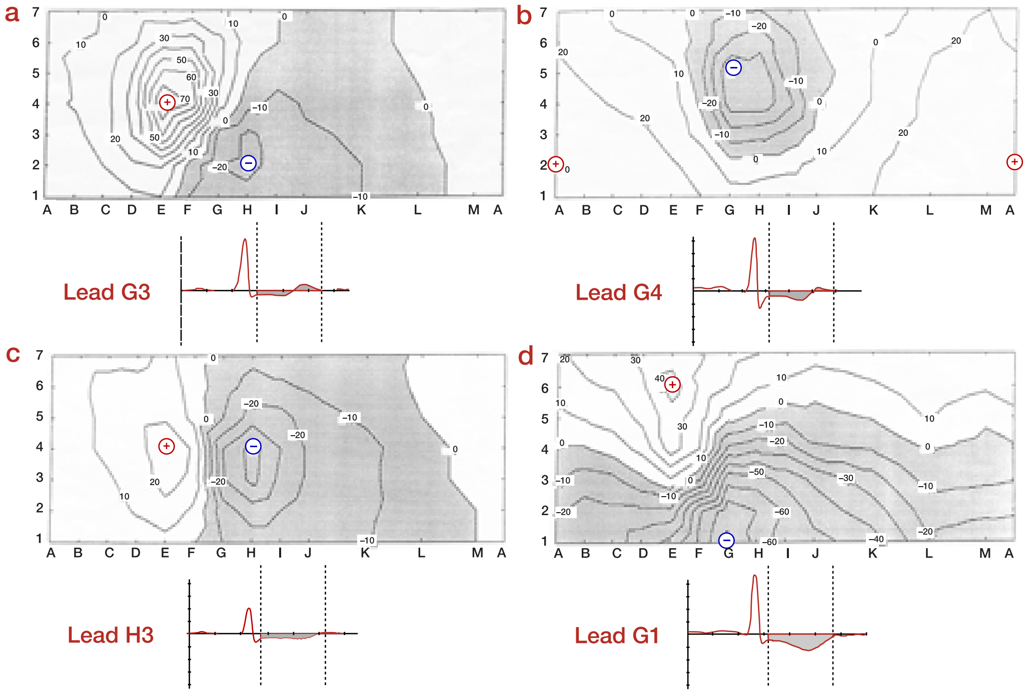

Fig. 3. Four types of abnormal negative areas in the postexercise ST-T isointegral maps in patients in group B. Isointegral contours are separated by 10 μV·s. Shading indicates negative areas. Significant area (< –10 μV·s) is located in the left-inferior and left-mid regions (**a**: 57-year-old man), in the left-mid and left-superior regions (**b**: 77-year-old woman), in all of the three left regions (**c**: 78-year-old man) or in both right and left regions (**d**: 73-year-old man).

points in which each isointegral value was less than –10 μV·s. The mean and mean –2SD difference maps between resting and postexercise QRST isointegrals in group A were constructed. When the QRST isointegral difference value was less than the mean –2SD in group A in at least 3 lead points, the decrease was considered significant (“–2SD area”). The correlation coefficient between resting and postexercise QRST isointegrals in 87 leads was used as a marker of similarities in the potential distributions.

Statistical analysis

Data are shown as the mean ± SD or as a percentage. For the comparison of statistical significance between 2 groups, the unpaired *t*-test was used. A value of $P < 0.05$ was considered significant.

Table 2. Relationship between significant area in the postexercise ST-T isointegral map and ischemic area in the thallium-201 myocardial imaging

Ischemic area	Significant area in the ST-T isointegral map			
	Left-inferior and left-mid [7]	Left-mid and left-superior [2]	All of the 3 left regions [4]	Right and left [4]
Anterior	2	0	0	2
Posterior	4	1	2	0
Anterior and posterior	1	1	2	2

[ ], number of patients.