Body Surface Electrocardiographic Mapping in Inferior Myocardial Infarction
Manifestation of Left and Right Ventricular Involvement

TERRENCE J. MONTAGUE, M.D., ELDON R. SMITH, M.D., C. ANNE SPEENCER, B.SC.,
DAVID E. JOHNSTONE, M.D., LUCILLE D. LALONDE, M.D., RICARDO M. BESSOUDO, M.D.,
MARTIN J. GARDNER, M.D., ROBERT N. ANDERSON, M.D.,
AND B. MILAN HORACEK, PH.D.

SUMMARY To determine the depolarization and repolarization time-integral patterns in patients with first acute inferior myocardial infarction, we acquired body surface potential maps in 28 men and eight women, ages 36–76 years, a mean of 76 hours after the onset of symptoms. Based on technetium-99m pyrophosphate myocardial scans, patients were divided into two groups. Group 1 included 22 patients with scintigraphic activity limited to the left ventricle who were considered to have exclusive left ventricular infarction, and group 2 included 14 patients with scintigraphic activity involving the right ventricle in addition to the left ventricle, considered to have both left and right ventricular infarction.

Isointegral plots of the first 50% of the QRS complex (Q zone) were characterized by negative areas over the inferior torso with concomitant extension of positive areas to the superior precordium. Group 2 patients had greater leftward and superior extension of the negative inferior distributions than group 1 patients. Subtraction of the mean Q-zone map of group 1 patients from that of group 2 patients confirmed a mean area of difference over the right anterior–inferior torso. The average Q-zone integral value within this area of difference was 5.9 ± 7.2 μV·sec (± sd) for group 1 patients compared with 1.7 ± 5.2 μV·sec for group 2 patients (p < 0.05). ST-segment isointegral maps revealed positive inferior distributions in all subjects; however, 29 patients also had abnormal negative ST-segment distributions over the precordium. The area of negative precordial values in group 2 patients extended further rightward and inferiorly compared with group 1 patients. There were two large areas of difference seen on subtraction: one over the precordium, in which the mean ST-segment integral value for group 1 patients was −0.6 ± 3.8 μV·sec, compared with −3.2 ± 3.2 μV·sec for group 2 patients (p < 0.025), and another over the inferior torso, where the mean value for group 1 was 1.2 ± 1.6 μV·sec, compared with 3.3 ± 3.5 μV·sec for group 2 (p < 0.05).

Thus, in acute inferior infarction, there is a characteristic distribution of negative Q-zone and positive ST-segment time integrals over the inferior torso and a reciprocal development of positive Q-zone and negative ST-segment integrals over the anterior-superior torso. Patients with right ventricular involvement, however, have spatial and quantitative abnormalities of both depolarization and repolarization that distinguish them from patients with infarction limited to the left ventricle.

THE INCREASED information content of body surface potential maps (BSPM) over standard electrocardiographic techniques offers promise that such maps may be useful in assessing patients with myocardial infarction. To facilitate efficient management of the mass of acquired data with BSPM, we have adopted techniques based on the measurement of various time integrals from each of multiple body surface ECG signals, with display in the form of isointegral contour maps. This approach, while providing effective data reduction, also retains much of the spatial information available from the more detailed instant-by-instant analysis of body surface potential maps. In addition, time-integral analysis techniques offer a convenient means of detecting abnormal portions of the P-QRS-T complex that require more detailed assessment.

In this study of patients with acute inferior infarction, we used isointegral analysis techniques to define the body surface distributions of early depolarization (Q-zone) and repolarization (ST-segment) time integrals. We also attempted to determine if the addition of right ventricular infarction, as compared to exclusive left ventricular involvement, has a significant influence on map appearances.

Subjects and Methods
All subjects gave informed consent before the study.

Patients with Myocardial Infarction
From a consecutive series of 51 patients admitted to the coronary care unit of the Victoria General Hospital over an 11-month period with an initial diagnosis of first acute inferior myocardial infarction, 36 patients fulfilled all of the following criteria and were selected as the study group. Twenty-eight were men and eight were women, ages 36–76 years. All had a history of ischemic-type cardiac pain compatible with a myocardial infarction; diagnostic cardiac enzyme elevations;
abnormal Q waves in at least two of leads II, III and aVF; presence of abnormal (2+ or greater, focal) scintigraphic activity involving the inferior-posterior left ventricular myocardial scans done within the first 72 hours of admission; a clinical status of Killip class I or II at the time of BSPM recordings; and absence of bundle branch block.

Normal Control Subjects
A control group of 51 clinically normal subjects, 40 men and 11 women, ages 20–46 years, was also recruited. None of these control subjects had a history of cardiac disease and all had normal physical and echocardiographic examinations and 12-lead ECG tracings.

Nuclear Imaging
After injection of technetium-99m pyrophosphate, analog images were obtained with a mobile Ohio Nuclear camera equipped with a low-energy, high-resolution, parallel-hole collimator. Images were obtained in the anterior, 45° left anterior oblique (LAO) and left lateral views to a total of 300,000 counts per image. Unprocessed analog images were interpreted by two independent observers blinded to other investigational results. The degree of radionuclide uptake in the myocardium was assessed according to the classification of Berman et al. In this system, the designation of 4+ = activity in the region of the myocardium greater than that of bone; 3+ = activity equal to bone; 2+ = activity less than bone; 1+ = slight activity; and 0 = no detectable activity. In addition, 2+ or greater activity was classified as focal or diffuse. As noted above, all study subjects had 2+ or greater focal scintigraphic activity in the region of the inferior-posterior left ventricular myocardium. Using the classification of Sharpe et al.,13 scintigraphic evidence of additional right ventricular infarction was considered present when, in the LAO view, 2+ or greater activity extended from the region of the heart toward the sternum, anterior to the interventricular septum. Final interpretation of myocardial images in this study represented the consensus of two observers.

Based on the results of the scintigraphic scans in the LAO view, the patients were divided into two groups. Group 1 included 22 patients with scintigraphic activity limited to the left ventricle, considered to have exclusive left ventricular infarction; and group 2 included 14 patients with scintigraphic activity involving the right ventricle as well as the left ventricle, considered to have both right and left ventricular infarction.

BSPM Recording
Our system of recording body surface ECG signals has been described. Briefly, digitized ECG signals are recorded simultaneously from 117 torso and three limb leads using Wilson's central terminal as reference, at a sampling rate of 500 samples/sec/channel. Each channel amplifier has a gain of 2000. With 10-bit samples, resolution is 10 μV for the least significant bit in the dynamic range of ±5 mV.

BSPM Processing
The ECG signals are processed off line on a Xerox Sigma 5 general-purpose computer.11 Selective averaging of 15 continuous seconds of recorded P-QRS-T

Figure 1. The averaged ECG signals recorded from 120 lead sites of a normal subject. The data are presented in analog format. The exact anatomic placement of the torso leads (0-116) is illustrated in figure 3. Briefly, the leads on the left of this figure represent the anterior torso and the leads on the right, the back. The column with leads 25-32 is placed over the midsternum, with lead 25 approximately over the larynx and lead 32 below the diaphragm. The column with leads 95-102 is placed over the dorsal spine, with lead 95 at approximately the C7 level. Leads 117-119 are recorded from limb sites, but for illustrative purposes are shown here superimposed on the left shoulder region.
All measurements of the various ECG time integrals are made from the averaged complexes at time instants determined from edited Frank X, Y and Z leads (fig. 2). Five time integrals were evaluated. The QRS time integral was calculated for each lead as the algebraic sum of all potentials from the time instant of QRS onset to QRS offset, multiplied by the sampling interval. This represents the net area under the curve, with the baseline as zero potential. The ST-T time integral was similarly calculated from the time instant of QRS offset to T offset; the QRST time integral represented the algebraic sum of the QRS and ST-T time integrals. The Q-zone time integral was calculated from the QRS onset to the midpoint of the QRS complex and the ST segment from the first three-eighths of the ST-T segment. Time integral units were expressed in $\mu V\cdot$sec.

For the purpose of this study, involving patients with acute myocardial infarction, analysis was concentrated on the Q-zone and ST-segment time integrals.

**BSPM Display**

The display format for individual and group-mean maps is illustrated in relation to torso and standard chest electrode sites in figure 3. The rectangular area represents the torso with both left and right margins representing the right midaxillary line. The left half of the map, therefore, represents the anterior torso and the right half, the back. Each contour line within the rectangle connects points of equal time-integral value. The solid contour lines represent positive values and the interrupted contour lines, negative values. The contour lines progress logarithmically from the zone of near-zero integral value with each decade line, as well as the maximum and minimum, numerically identified. The torso electrodes are represented by dots; the 12-lead ECG $V_j-V_6$ electrode positions, by squares.

The subtraction, or difference, maps were also displayed in logarithmic isointegral contour format. The solid lines in these maps, however, represent areas in which one study group had relatively greater integral values compared with the other group. Interrupted lines in intergroup difference maps represent areas where one group had relatively lower integral values compared with the other group.
Study Protocol

All BSPMs were recorded in the coronary care unit with the subjects in the supine position. At the time of recording, all control and study subjects were in sinus rhythm.

Individual time-integral maps, including Q-zone, QRS, ST-T, ST segment and QRST, were plotted for all subjects. Group-mean maps were also constructed using the respective mean values at each lead site. To further characterize differences between patients with exclusive left ventricular involvement and those with additional right ventricular involvement, the group 1 mean Q-zone and ST-segment time-integral maps were subtracted from the corresponding group 2 mean maps. The resulting subtraction, or difference, maps spatially localized the mean Q-zone and ST-segment areas of difference between the two patient groups. These mean areas of difference identified by the subtraction process also served as areas of interest for individual subjects, with the average value of the Q-zone and ST-segment time integrals within these areas being calculated for each patient in each group.

Intergroup comparisons of Q-zone and ST-segment area of difference values were by t test for unpaired observations.

Results

Figure 4 is a comparison of the mean Q-zone, QRS, ST-T, ST-segment and QRST isointegral maps for the 36 inferior infarction patients and the corresponding mean maps constructed from the control sample of 51 normal adult subjects. Both normal and patient groups had similar sex distributions. Compared with normal subjects, patients with inferior infarction demonstrated negative Q-zone areas over much of the inferior chest and extension of positive Q-zone areas to the superior chest. Although there was some individual variation, all patients with acute inferior infarction displayed areas of negative Q-zone values over the inferior torso (fig. 5). The inferior torso negativity displayed by the early depolarization time integral (Q zone) was also reflected in the QRS integral maps, although there was greater individual variability in QRS distributions compared to Q-zone plots. Similarly, ST-T plots showed greater individual variability than ST-segment distributions. ST-segment integral distributions in the infarction patients tended to be positive inferiorly and negative anteriorly — 29 of the 36 patients had areas of negative precordial ST-segment distributions. QRST maps showed wide variation among individual patients; however, only five patients had non-dipolar distributions. Over the inferior torso, there was a relative concordance of the areas of negative Q-zone and positive ST-segment distributions (fig. 4). A similar relative concordance was observed anteriorly between areas of increased Q-zone positivity and ST-segment negativity.

Representative individual and group-mean Q-zone and ST-segment time-integral distributions of group 1 patients are compared to those of group 2 patients in figures 5 and 6. The spatial distributions of Q-zone integrals were similar in the two groups, probably reflecting the dominance of the left ventricular injury; however, patients in group 2 tended to have a greater area of negative Q-zone distribution over the right anterior-inferior chest. Groups 1 and 2 also had similar ST-segment distributions, but group 2 patients tended to have greater inferior and rightward extension of negative anterior distributions and more superior extension of inferior positive patterns, particularly over the right chest.

Using as criteria of right ventricular infarction a Q-zone map pattern similar to the mean plot illustrated in figure 6, blinded, retrospective analysis of individual Q-zone maps of all infarction patients revealed a positive predictive value for the presence of right ventricular infarction of 69% and a negative predictive value of 78% (overall predictive accuracy 75%). Similar retrospective analysis of all individual ST-segment isointegral maps, using the spatial pattern of the group 2 mean maps as the criteria of right ventricular involvement, gave a positive predictive value of 35%.

The Q-zone isointegral difference map is illustrated in figure 7. As might be expected from comparison of the group-mean Q-zone maps (fig. 6), the major Q-zone area of difference between the patient groups was located over the anterior-inferior torso. In this area, the average Q-zone value of group 2 patients was significantly (p < 0.05) less (mean 1.7 ± 5.2 [± SD] μV·sec) than that in group 1 patients (5.9 ± 7.2 μV·sec); that is, in this area, group 2 patients had more negative Q waves or less positive R waves than group 1 patients. In the small area of difference located over the precordium, both groups had similar integral values (12.8 ± 4.7 μV·sec for group 1 patients vs 13.7 ± 5.1 μV·sec for group 2 patients, NS).

The ST-segment time integral difference map (fig. 8) demonstrates a precordial area of difference in which the group 2 patients had significantly (p < 0.025) more negative values (−3.2 ± 3.2 μV·sec) than group 1 patients (−0.6 ± 3.8 μV·sec). In the area of difference over the right inferior chest, group 2 patients had significantly (p < 0.05) more positive ST-segment integral distributions (3.3 ± 3.5 μV·sec) than group 1 patients (1.2 ± 1.6 μV·sec).

Differences in Q-zone and ST-segment distribution can also be appreciated by comparing a representative 120-lead ECG plot of a patient with exclusive left ventricular infarction to that of a similar plot from a patient with additional right ventricular involvement, as shown in figure 9. These plots are from the same patients illustrated in figure 5. In particular, the patient with right ventricular involvement (fig. 9B) demonstrates a relatively greater area of negative Q zones (deeper, more negative Q waves) in the right anterior-inferior leads, while the patient with exclusive left ventricular infarction (fig. 9A) shows more positive ST segments in the inferior leads.

Discussion

The increased information available with BSPM suggests that it may be valuable in the assessment of
patients with acute myocardial infarction. Flowers et al., using serial isopotential maps, studied 22 patients 2-4 weeks after inferior-posterior myocardial infarction and noted large zones of QRS positivity over the left anterior superior chest and areas of QRS negativity over the lower chest, distributions not appreciated by conventional ECG methods. In a study of 84 patients with old myocardial infarction, Vincent and co-workers also noted an increased ability of the body surface map to diagnose remote inferior myocardial infarction. Others who have specifically studied repolarization patterns in acute myocardial infarction have stressed the increased sensitivity and desirability of total body surface mapping techniques compared with conventional ECGs, or partial torso maps, for the assessment of infarct size. In a previous study, we found isointe-
EXCLUSIVE LV INFARCTION

LV AND RV INFARCTION

Q-ZONE

ST

FIGURE 5. Q-zone and ST-segment isointegral plots, from a patient with exclusive left ventricular (LV) infarction (left) and a patient with biventricular involvement (right). Note the resemblance of these representative individual Q-zone and ST-segment maps to the group-mean Q-zone and ST-segment maps illustrated in figure 6.

torial BSPM analysis useful in monitoring depolarization and repolarization changes during the early evolution of acute myocardial infarction. The results of the present study extend our application of BSPM techniques in the setting of acute myocardial infarction.

In this study, using isointegral techniques, we found that patients with acute inferior infarction have a zone of negative Q-zone distribution over the inferior torso with increase in positivity over the anterior-superior torso. ST-segment distributions were characterized by negative inferior torso positivity and anterior torso negativity. These concomitant, but vectorally opposite, depolarization and repolarization time-integral torso patterns were observed in most of our patients. Previous studies using conventional electrocardiographic techniques have also noted an opposing pattern of anterior and inferior ST-segment distributions in some patients with acute inferior myocardial infarct-

EXCLUSIVE LV INFARCTION

LV AND RV INFARCTION

Q-ZONE

ST

FIGURE 6. Comparison of the mean Q-zone and ST-segment isointegral plots from 22 patients with exclusive left ventricular (LV) involvement and 14 patients with additional right ventricular (RV) involvement during acute inferior myocardial infarction. Patients with RV involvement tended to have a greater area of negative Q zone over the right anterior-inferior torso and greater inferior and rightward extension of negative anterior ST-segment distributions.
Among our patients, the high prevalence of concomitant anterior torso ST-segment negativity and inferior torso positivity, together with a similar high prevalence of anterior positive and inferior negative Q-zone distributions, suggests that both patterns represent true reciprocal electrocardiographic changes. These reciprocal effects in both depolarization and repolarization are presumably due to the loss of balancing or canceling wave fronts consequent to the area of acute inferior myocardial injury. However, some of the apparent reciprocal anterior torso Q-zone and ST-segment changes may also be due to coexistent anterior ischemia or anterior wall motion abnormalities. Further studies correlating regional torso ECG distributions, regional myocardial wall motion and underlying coronary anatomy are required.

Previous studies using abnormal elevation of ST-segment distributions in right-sided precordial leads suggest that the ECG can reflect right ventricular involvement in inferior myocardial infarction. More recent studies have confirmed that early, transient ST-
segment elevation in lead V₄R is a sensitive and specific indicator of right ventricular involvement in inferior myocardial infarction. It does appear critical, however, that V₄R be recorded early in the course of infarction to retain its predictive value for right ventricular involvement. Body surface isopotential maps have also been used on an experimental basis for the diagnosis of right ventricular infarction in dogs. Canine studies have revealed that dogs with exclusive right ventricular infarction had, during the early and middle stages of ventricular depolarization, negative distributions over the right anterior chest surface. Our data reveal that there are differences in surface electrocardiographic patterns of early depolarization (Q-zone) and early repolarization (ST-segment) time integrals between patients with exclusive left ventricular involvement and patients with biventricular involvement in acute inferior myocardial infarction. Although collectively a detectable effect of right ventricular infarction was evident on group-mean BSPMs, the predictive value of identifying any particular patient as having right ventricular involvement, at least by retrospective BSPM pattern analysis, was only moderately reliable (69% with Q-zone pattern recognition). At the relatively late point in infarction evolution at which the BSPMs were recorded in this study, the depolarization time-integral (Q-zone) pattern was of more discriminative value, however, than assessment of the repolarization (ST-segment) pattern (positive predictive value of 35%). Further prospective studies are required to as-

**Figure 9.** The averaged ECG signal, in analog format, at each of the 120 lead sites from a subject with exclusive left ventricular infarction (A) and from a patient with additional right ventricular infarction (B). The display format is the same as figure 1. Leads 19, 28 and 36 in map B have been edited, 19 and 28 because of an obvious incorrect wave form and 36 because of incorrect positioning of baseline. These plots are from the same subjects whose Q-zone and ST-segment isointegral plots are illustrated in figure 5.
sess whether Q-zone or ST-segment maps acquired earlier in the evolution of inferior infarction would allow better individual discrimination between patients with exclusive left ventricular involvement and those with additional right ventricular involvement.

In conclusion, body surface ECG maps provide unique data in patients with myocardial infarction. In particular, inferiorly located myocardial infarction or injury is well reflected in its ability to distinguish them from patients with exclusive left ventricular involvement. Although the results of this study are preliminary, the ability of difference maps to locate areas of interest for quantitative analysis offers promise that application of this or related techniques may be of value in the assessment of the size of myocardial injury and its change with time or with interventions.

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