Electrocardiographic and Scintigraphic Imaging of Myocardial Ischemia

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Abstract

The aim was to further validate the electrocardiographic imaging method we introduced previously—involving inverse calculation of heart-surface potential distributions from the 12-lead ECG—by comparison with data provided by single photon emission computed tomography (SPECT). To perform the electrocardiographic inverse solution, we used a torso model with 352 body-surface and 202 heart-surface nodes. Coefficients for estimating 352 body-surface potentials from 12-lead ECG were developed from the design set (n = 892) of body-surface potential mapping (BSPM) data. The test set consisted of 12-lead ECGs of 31 patients from the STAFF III dataset (Duke University Medical Center; Lund University) who underwent elective percutaneous coronary intervention (PCI) of the LAD (n = 8), LCx (n = 5), or the RCA (n = 18) and had SPECT performed. BSPM distributions at J point were estimated from the 12-lead ECG and used to calculate bull's-eye displays of heart-surface potentials. The latter displays were found to have the area of positive potentials corresponding in all but 2 cases with the underperfused territory indicated by SPECT. For the LAD and LCx groups all ECG-derived bull's-eye images featured positive potentials in the expected territory and were consistent with SPECT images; for the RCA group 13/18 ECG-derived bull's-eye images indicated the expected territory, but 3/5 of "misclassified" cases were consistent with SPECT images. Therefore, our findings suggest that electrocardiographic imaging based on just the 12-lead ECG might yield estimates of myocardial ischemic regions that are consistent with those provided by SPECT.

1. Introduction

Electrocardiographic monitoring allows noninvasive detection of both cardiac ischemic and arrhythmic events. It has been widely used for detecting myocardial ischemia in patients with unstable coronary syndromes and it contributes significantly to the reduction of mortality in these patients [1]. Most bedside monitors allow continuous monitoring by means of the 12-lead ECG and thus the challenge is to make the best use of this information. Lux *et al.* [2] hypothesised that BSPM distributions estimated from reduced lead sets (e.g., the 12-lead ECG) can provide more information than the original leads alone. In a previous study [3], we examined the spatial BSPM patterns recorded during elective balloon-inflation PCI in 45 patients with single-vessel coronary artery disease to determine how well these patterns can be predicted from the 12-lead ECG. By using the electro-cardiographic inverse solution, we also estimated heart-surface potential maps from BSPM data derived, in turn, from the 120-lead and 12-lead ECGs. In a more recent study, we cross-validated the method introduced previously [3] by qualitatively comparing, for 18 patients, the maps of heart-surface potentials derived from the 12-lead ECG with estimates of acute ischemia obtained by scintigraphic perfusion imaging [4]. The aim of the present study was to further validate our electrocardio-graphic imaging method by using the STAFF III [5, 6] dataset consisting of both 12-lead ECG and scintigraphic data.

2. Methods

2.1. Patient population

The design set for developing the transformation from the 12-lead ECG to BSPM distributions was the Dalhousie Superset consisting of 120-lead ECGs from 892 subjects [7]. The test set was a patient population from the STAFF III database, which consisted of the ECG and scintigraphic data for patients studied at the Charleston Area Medical Center in West Virginia, who underwent elective PCI (using a non-perfusion balloon and mean occlusion time of 5 minutes) [5, 6]. All of these patients had continuous 12-lead ECG recorded before and throughout the PCI procedure. For the present study, we used a subset of 31 patients for whom there were SPECT data available; this subset comprised 8 with LAD occlusion, 5 with LCx occlusion, and 18 with RCA occlusion.

2.2. ECG acquisition and processing

The 12-lead ECG was digitally recorded for each patient by a Siemens-Elema (Solna, Sweden) cart at 1 kHz sampling rate with a resolution of 0.6 μV for the least-significant bit [5, 6]. Signal processing was done at Dalhousie University on an RS/6000 computer (IBM Corp, Armonk, NY). We used data of 10 seconds during peak ischemia at the end of balloon inflation, just before reperfusion. QRS onset was determined for each beat, to establish the baseline, and the QRS offset was designated as J point. ST deviation was the difference between amplitude at J point and at the baseline; these values were then averaged for all beats within a 10-second period. The values of 352 body-surface potentials corresponding to the nodes of the 3D torso model [8] were then estimated from the 12-lead ECG to get the BSPM distributions (see maps in upper panels of Figs. 1–3). The transformation from the 12-lead ECG to 352-node BSPM distributions was developed by application of linear regression analysis (procedure PROC REG in the SAS System), using the Dalhousie Superset [7] as the design set. Epicardial potential maps were calculated for 202 nodes from the 352-node BSPM distributions by means of the inverse solution [8], and displayed on polar projections [9] of the epicardial surface (see middle panels of Figs. 1–3).

2.3. SPECT acquisition and processing

During coronary occlusion, ^{99m}Tc-sestamibi was injected intravenously in each patient. The scintigraphic SPECT images for the "occlusion state" were then obtained within 3 hours, using a single-head rotating gamma camera (Elscint, Haifa, Israel). The acquisitions were made with a high-resolution collimator in a 64 × 64 matrix, 6.9 mm pixel size, using 30 projections over 180° (from 45° right anterior oblique to 45° left posterior oblique). With the use of filtered back-projection with Butterworth filter, transverse sections were reconstructed and short-axis sections were saved for further analysis [6, 10]. To establish a SPECT "baseline image," radionuclide was re-administered approximately 24 hours after the PCI and the images were obtained 2–3 hours later with the same gamma camera and protocol as for the PCI acquisition. The Cedars-Sinai and Emory analysis program (CEqual, ADAC Laboratories, Milpitas, CA) [11] was used for making volume-weighted bull's-eye plots from the short-axis sections. The polar plots were analyzed using in-house software (Segment 1.688; http://segment.heiberg.se). Any loss of perfusion during an "occlusion state" compared to the "baseline state" was determined by subtracting the corresponding bull's-eye images [10].

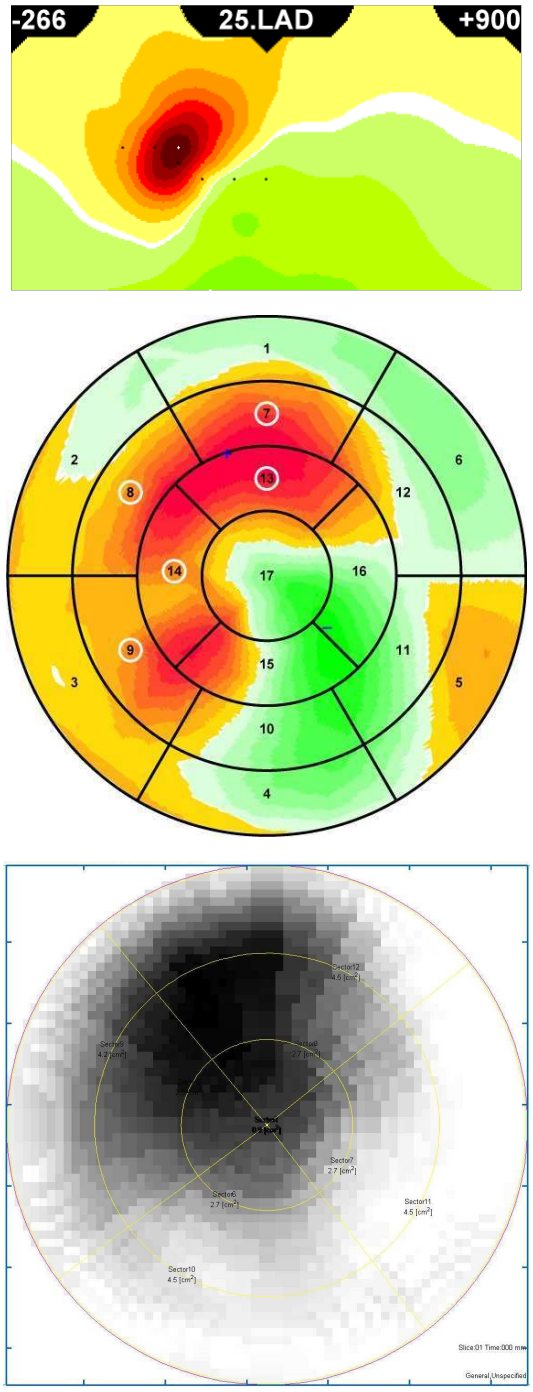

Figure 1. Body-surface (top) and heart-surface (middle) potential maps estimated from the 12-lead ECG compared to the SPECT image (bottom) for the LAD occlusion. Potential maps feature areas of positive (yellow to red) and negative potentials (green), dynamically scaled to 8 isopotential levels between zero and the larger extremum (max/min); SPECT difference map uses gray scale for counts from zero (black) to maximal counts (white).

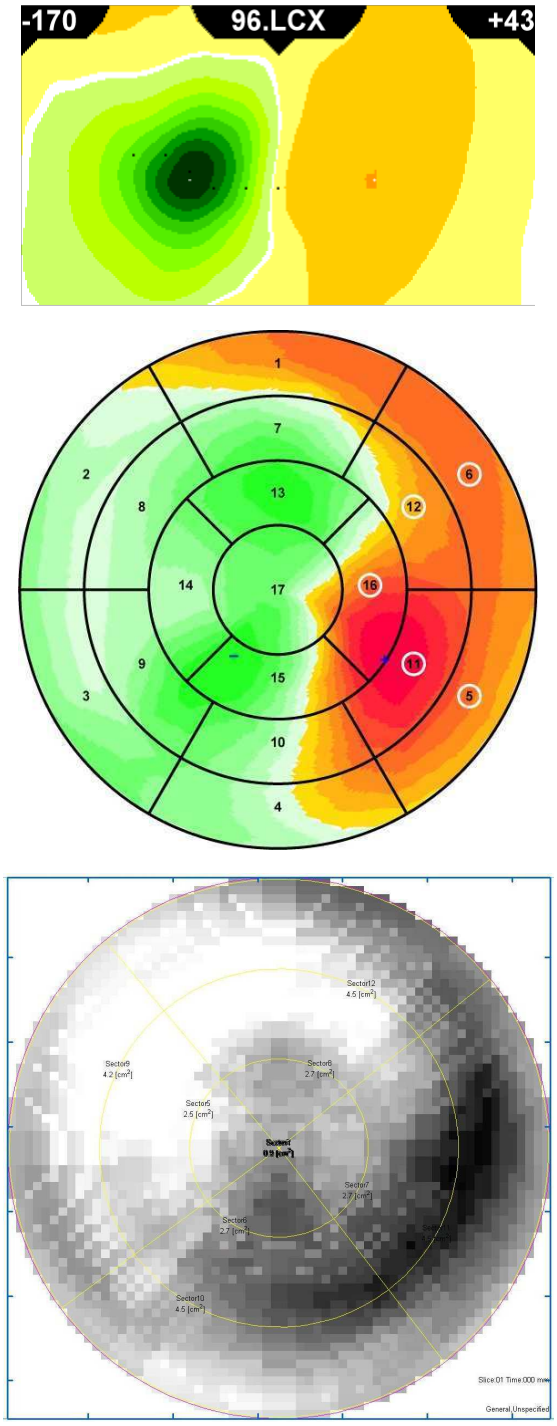

Figure 2. Body-surface and heart-surface potential distributions estimated from the 12-lead ECG compared to the SPECT image, all corresponding to the LCx coronary artery occlusion. The same display format as in Fig. 1.

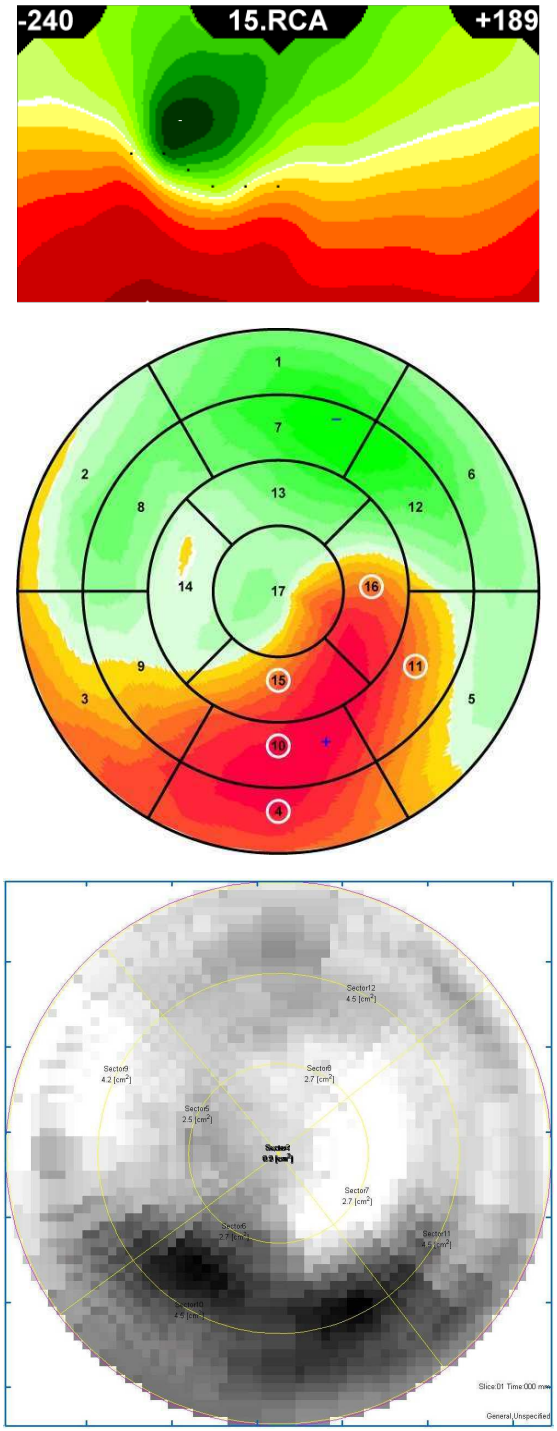

Figure 3. Body-surface and heart-surface potential distributions estimated from the 12-lead ECG compared to the SPECT image, all corresponding to the RCA occlusion. The same display format as in Fig. 1.

3. Results

Heart-surface potentials derived from the 12-lead ECG had an area of positive potentials that corresponded with the SPECT-indicated hypoperfused territory. For the LAD and LCx groups, all ECG-derived bull's-eye images indicated the expected territory and were consistent with SPECT images; for the RCA group only 13/18 ECG-derived images indicated the expected territory, but 3/5 "misclassified" cases were consistent with SPECT. Fig. 1 compares electrocardiographic and scintigraphic images during occlusion of LAD. The upper panel shows a body-surface potential map estimated from the 12-lead ECG measurements at J point of an ST-elevation myocardial infarction (STEMI) case; the middle panel shows a heart-surface potential map computed from the distribution in the upper panel; for this map, 4/5 segments (7, 8, 13, 14) with the largest sum of positive deflections are in the LAD territory as defined by AHA [9]. The bottom panel shows a scintigraphic polar difference map corresponding to the episode of LAD occlusion captured by the electrocardiographic images. Fig. 2 compares electrocardiographic and scintigraphic images during occlusion of LCx. The middle panel delineates clearly the ischemic region, with all 5 segments (5, 6, 11, 12, 16) with the largest sum of positive deflections in the LCx territory [9]. Fig. 3 compares electrocardiographic and scintigraphic images for occlusion of RCA. It is a STEMI case. For heart-surface potential map in the middle panel, 3/5 segments (4, 10, 15) with the largest sum of positive deflections are in the RCA territory and 2 are in LCx territory [9]. A scintigraphic polar difference map in the bottom panel confirms that the underperfused RCA region extends, in fact, to the LCx territory.

4. Discussion

We have shown that heart-surface potential maps can be estimated by the inverse solution from the 12-lead ECG and that such maps can detect and localize acute myocardial ischemia. Acute occlusion of the LCx, as represented by Fig. 2, typically produces regional ischemia in the posterolateral left ventricular free wall that fails to be represented by ST elevation in any of the 12 standard ECG leads. Instead, ST depression is present in leads V1 and V2. This may lead to the incorrect diagnosis of "anteroseptal subendocardial injury" rather than the correct diagnosis of "posterolateral epicardial injury" and, therefore, the patient may not receive the potentially beneficial emergency reperfusion therapy. This study suggests that heart-surface potential maps derived (via body-surface potential maps) from the 12-lead ECG by means of the electrocardiographic inverse solution may provide a noninvasive method for correctly detecting and localizing regional myocardial ischemia during occlusion of any of the 3 major coronary arteries. Therefore, it is possible that this mapping technique will be useful in the management of patients suffering from acute coronary syndromes.

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