Inference of Epicardial Potentials from Multipolar Equivalent Sources Using Aimed Leads

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ABSTRACT

Epicardial potentials are commonly inferred by calculating coefficients, which directly link epicardial and body surface potentials, via the boundary-element method (BEM). Epicardial potentials may also be found from multipolar cardiac-equivalent sources using the aimed-lead method (ALM). Because the inverse solution for the multipolar-sources in the ALM need not be dependent on heart geometry and may meet correlation constraints assumed for many regularization techniques better than the BEM, we hypothesized that the ALM may yield more accurate estimates of epicardial potentials than the BEM. To test the performance of each method, we compared ALM and BEM solutions in a 5-layer epicardial model with a dipole layer source. With optimal Tikhonov regularization, no noise, and no errors in geometry, the relative error for the ALM and BEM was 0.27 and 0.29, respectively. When 5% Gaussian noise (BEM noise value/BMS potential value) was added to body-surface potentials, the relative error for the ALM and BEM was 0.32 and 0.34, respectively. With optimal regularization, no noise, and an error of ±1 cm in the location of the heart, the relative average error for the ALM and BEM was 0.36 and 0.41, respectively. Both ALM and BEM were also applied to body-surface measurements of an adult male with a pacemaker. The pacing electrode was implanted at the interventricular septum. Torso geometry, the location of 150 electrodes, and the location and orientation of the transducer of an ultrasound probe used to image the torso were measured to within ±0.1 cm with an Immersion Personal Digitizer. Torso geometry was approximated by a 2nd-degree-spherical-harmonic model. The heart was modeled as a sphere with a radius of 2.79 cm. At 10 ms after pacing, the distance from the pacing electrode to the minimum of the epicardial map for the ALM and BEM was 1.07 cm and 1.09 cm, respectively. These results suggest that inference of epicardial potentials with multipolar equivalent sources may yield improved estimates of epicardial potentials if appropriate regularization techniques can be devised for them.

AIMED LEAD METHOD (ALM) VS DIRECT BOUNDARY ELEMENT METHOD (BEM)

1. The direct inference of epicardial potentials using the boundary element method (BEM) has been carefully studied; yet, even with optimal regularization, relative errors between inferred and actual epicardial potentials range from 0.43 to more than 1 when applied to humans.
2. In the aimed-lead method (ALM), epicardial potentials are inferred from weighted sums of multipolar cardiac-equivalent sources.
3. Determining epicardial potentials from multipolar sources may improve potential estimates because multipolar terms:
   **• Need not be dependent on heart geometry.**
   **• May be better regularized because they are more likely to be uncorrelated than epicardial potentials.**

OBJECTIVES

1. Compare the ability of the ALM and BEM to infer epicardial potentials in an eccentric spherical model using optimal Tikhonov regularization in the presence of:
   **• Errors in heart location**
   **• Noise in body surface potentials**
2. Demonstrate and test the use of the ALM and BEM to infer epicardial potentials in humans.

METHODS

1. Inverse Problem

\[ \mathbf{P} = \mathbf{R} \mathbf{A} \mathbf{U} \]

where the entries of \( \mathbf{A} \) are 1 for the multipolar source, 0 for the torso. Cardiac source potentials were represented by a 10-sphere layer (n = 10). Hypothetical potentials were generated with 5% Gaussian noise.

2. Forward Problem

\[ \mathbf{U} = \mathbf{A} \mathbf{P} \]

Forward problem coefficients were calculated assuming:

- Torso symmetric with respect to the frontal plane.
- Torso symmetric with respect to the sagittal plane.
- Torso symmetric with respect to the transverse plane.

3. Epicardial potentials were calculated using the ALM and BEM with optimal Tikhonov regularization, when torso potentials were:

- Calculated with a different eccentricity of the heart than was assumed for the forward problem coefficients.
- Corrupted with Gaussian noise.

RESULTS

**Inference of Epicardial Potentials**

**Eccentric Spheres Study**

**Application to Humans**

**RESULTS**

**Epicardial Potentials: ALM**

- Without regularization, the location of the pacing lead was not apparent in the inferred epicardial potentials for either the ALM or BEM.
- With regularization, epicardial potentials were visible on an activation front near the pacing site.

**Epicardial Potentials: BEM**

- With multipolar-equivalent sources and appropriate regularization may yield improved estimates of epicardial potentials.