Analyzing Source Sampling to Reduce Error in ECG Forward Simulations

Jess Tate[1], Nejin Zemzemi[2], Wilson Good[1], Peter van Dam[3],
Dana Brooks[4], Rob MacLeod[1]

[1]University of Utah, Salt Lake City, Utah, USA
[2]Inria Bordeaux Sud Ouest, France
[3]Radboud Nijmegen University, The Netherlands
[4]Northeastern University, Boston, MA, USA

Abstract

ECG Imaging (ECGI) is the process of calculating electrical cardiac activity from body surface recordings from geometry and conductivity of the torso volume. Therefore, the accuracy of ECGI may be sensitive to the geometric representation of the thorax. Cardiac surface segmentation key, yet possibly variable, part of most ECGI pipelines. We hypothesis that variation in cardiac segmentation will produce error in the computed ventricular surface potentials from ECGI. In this study, an international consortium performed multiple segmentations of the same patient to analyze the effect on the results of ECGI.

We compared ECGI results from the same body surface potentials and multiple ventricular segmentations. Through a collaborative effort within the Consortium for ECG Imaging (CEI), a patient CT scan was segmented by five research groups, from which we created ventricle and torso surface meshes. We computed epicardial and endocardial surface potentials from measured body surface potentials with Tikhonov regularization and calculated the variance of the potential at each point of the ventricular surface.

We found that using the different segmentations produced variability in the computed ventricular surface potentials. The peak computed variance was up to 50 mV^2. In general, the anterior surface showed greater variance in the computed potential than the posterior surface, and the epicardium showed greater variance than the endocardium. Not surprisingly, locations of greater variance in the computed potential correlated to locations of greater variance in the segmentations, for example near the pulmonary artery and basal anterior left ventricular wall.

Our result indicate that ECGI may be more sensitive to segmentation errors on the anterior epicardial surface than other areas of the heart. A hypothetical rationale for this finding is that in the anterior region, the heart and body surface are closest together so that even small distance perturbations would alter computed cardiac potentials.

1. Introduction

ECG Imaging (ECGI) is the process of calculating electrical cardiac activity from body surface recordings from geometry and conductivity of the torso volume. Though many of the techniques used in ECGI are well established, the uncertainty of these techniques are not well quantified.

Uncertainty in ECGI could arise in many of the various stages performed in most ECGI pipelines, yet segmentation of the patient geometry may be the step that requires the most user judgement. Therefore, segmentation is a potential origin of error and uncertainty in the ECGI pipeline.

We have previously shown that segmentations of the same patient geometry, especially of the cardiac surface, can vary widely with each user [1]. However, it is not fully understood how this variability will affect the end result of the ECGI pipeline. We hypothesis that variation in cardiac segmentation will produce error in the computed ventricular surface potentials from ECGI. In this study, an international consortium performed multiple segmentations of the same patient to analyze the effect on the results of ECGI.

2. Methods

We compared ECGI results from the same body surface potential maps (BSPM) and multiple ventricular segmentations. The patient data used in this study was collected by Sapp *et al.*[2] and has been made available on the EDGAR database (http://edgar.sci.utah.edu) [3].

A patient scan was supplied to five research groups, who then supplied segmentations of the heart. The STAPLE algorithm [4] was used to generate an aggregate segmentation. Each of the segmentations were used to make surface meshes and were registered to an existing torso surface mesh using a modified iterative closest point registration.

Epicardial and endocardial surface potentials were com-

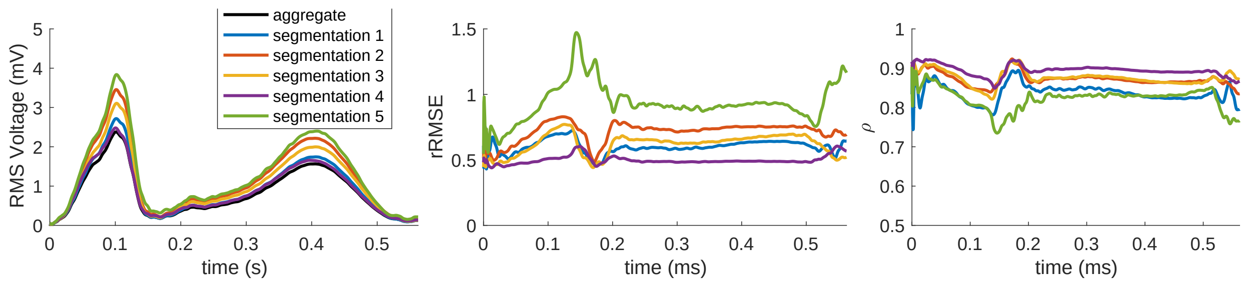

Figure 1. Error of the ECGI potentials with various segmentations compared the aggregate solution.

puted with Boundary element method and Tikhonov regularization as implemented in the Foward/Inverse toolkit in SCIRun (scirun.org) [5–7]. Computed source potentials were mapped onto the aggregate heart geometry for pointwise comparison. We have compared the computed potentials from each of the segmentations to the potentials from the aggregate segmentation using the correlation coefficient and relative root mean squared error. We also computed the variance at each over the surface of the heart and through the recorded beats.

3. Results

Comparing computed endocardial and epicardial potentials from each of the segmentations to the aggregate potentials showed varied accuracy. As shown in Figure 1, each of the metrics varied over time and with differing segmentations. The mean correlation of the computed potentials compared to the aggregate potentials ranged from 0.79 to 0.89 and the relative root mean squared error ranged from 0.52 to 0.96.

Comparing the variance of computed endocardial and epicardial potentials over the surface of the heart reveal consistent areas of higher variation. As shown in Figure 2, the anterior surface generally has higher mean variance in the computed potentials than posterior surface. The epicardial surface also has a higher variance than the endocardial surface. Not surprisingly, locations of high variance in the potential correspond to locations of greater variability of the segmentations, for example near the pulmonary valve and the basal, anterior, left ventricular wall. However, some locations, such as the basal, posterior wall and the endocardial, right ventricular apex, showed lover variance of the potentials despite showing high variation in the segmentation.

4. Discussion

Our results indicate that the cardiac potentials computed using ECGI may be sensitive to variability in the cardiac segmentations. However, some regions of the heart are more sensitive to perturbations in the cardiac segmentation than other, *i.e.* the anterior surface of the heart. This is likely because the distance between the heart and torso surfaces is much smaller on the anterior cardiac surface than other locations in the heart. These findings also support a growing concern regarding the need to quantify the uncertainty of simulations and, in this case, segmentation steps. Better quantification of the segmentation in this regard will drive better ECGI solutions and provide context in clinical settings.

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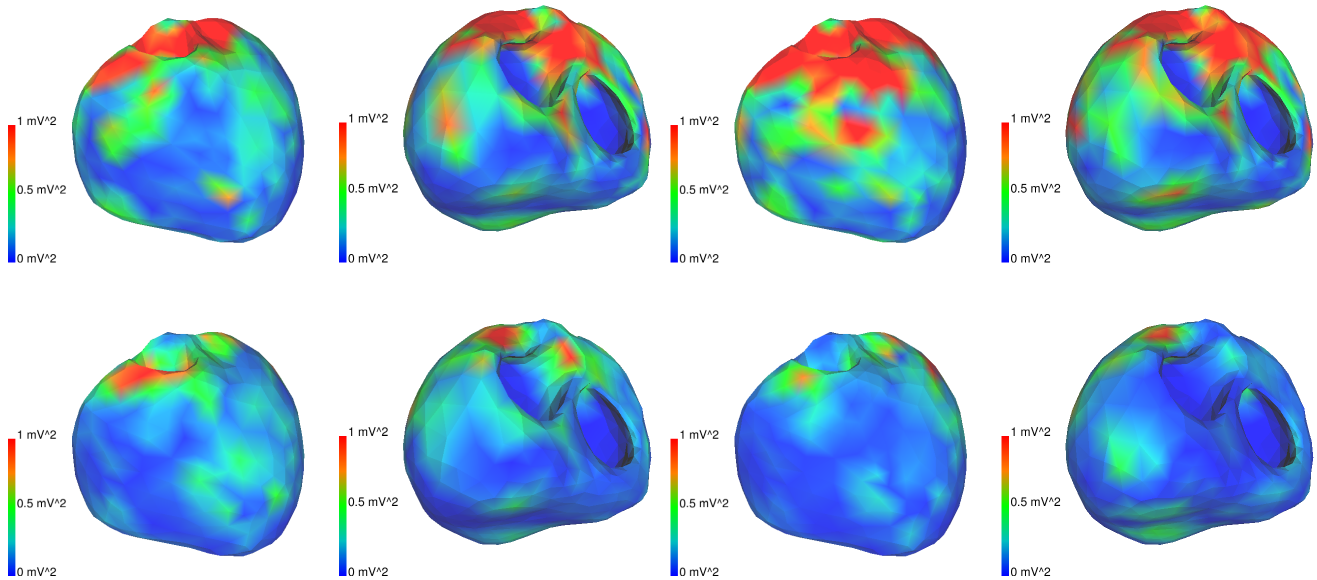

Figure 2. Mean variance by location due to the differing segmentations for example beats.

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Address for correspondence:

Jess Tate
Scientific Computing and Imaging Institute
WEB, 72 South Campus Drive, Rm 3750
Salt Lake City, UT 84112
jess@sci.utah.edu