Measurement of Defibrillator Surface Potentials for Simulation Verification

Jess Tate[1,2], Jeroen Stinstra[2], Tom Pilcher[3], Rob MacLeod[1,2]

[1]Department of Bioengineering, University of Utah, Salt Lake City, USA
[2]Scientific Computing and Imaging Institute (SCI), University of Utah, Salt Lake City, USA
[3]Primary Children's Medical Center, Salt Lake City, USA

Introduction

Implantable cardioverter defibrillators (ICD) are used to prevent fatal arrhythmias, and have become increasingly more common [1]. Though these devices are considered a mature technology, they are not optimized for use in pediatrics or patients with abnormal geometries [2], nor are they optimized to prevent excessive energy output, which can cause unnecessary damage [3].

We have developed a simulation to predict the electric field during the discharge of the ICD and calculate the energy required for defibrillation [4]. Verification of the simulation in humans is sought by comparing the surface potentials generated by the simulation with actual surface measurements from the ICDs. However, the empirical measurements can only be taken during the implantation surgery of the ICD when the device is tested.

Using limited a lead selection algorithm and body surface potential mapping [5], we have developed a set of optimum lead locations to obtain the full surface potential map of an ICD discharge using 32 leads. Using the 32 lead system, we have measured the ICD surface potentials from a patient and compared the simulation surface potentials from the specific patient geometries. Comparisons show similar distribution of the electric field over the torso surface between the simulation and the measurements.

Methods

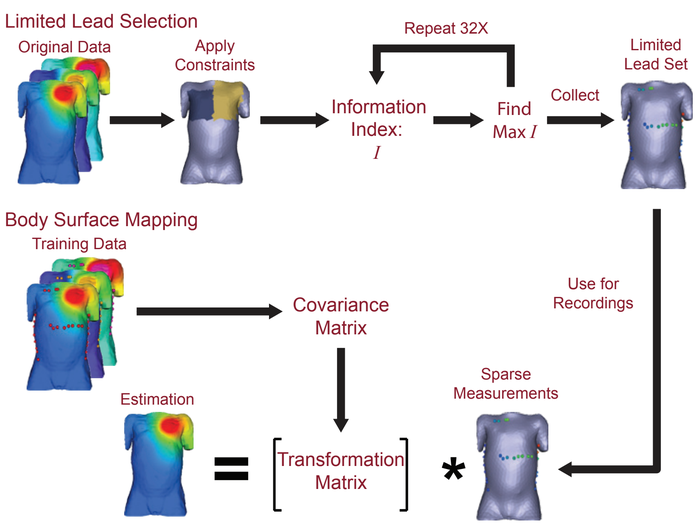
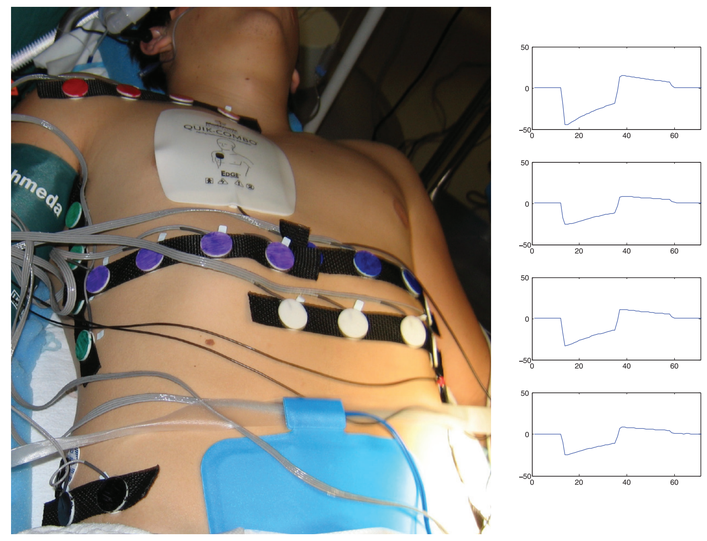


Figure 1. Limited Lead Selection and Body Surface Mapping. Body surface mapping is based on the statistical characteristics of a known set of torso potentials, specifically the covariance and standard deviation. With surface mapping, the full torso measurements can be taken using only 32 lead locations. The lead locations were chosen based on the information index obtained from the covariance and the standard deviation. For full explanation of the algorithm, refer to Lux, et al. [5]

Figure 2. Obtaining the surface recordings for the limited lead selection algorithm. 32 surface leads are placed for recordings and the amplitude is used in the estimation algorithm. An example of the recordings are also shown.



Results

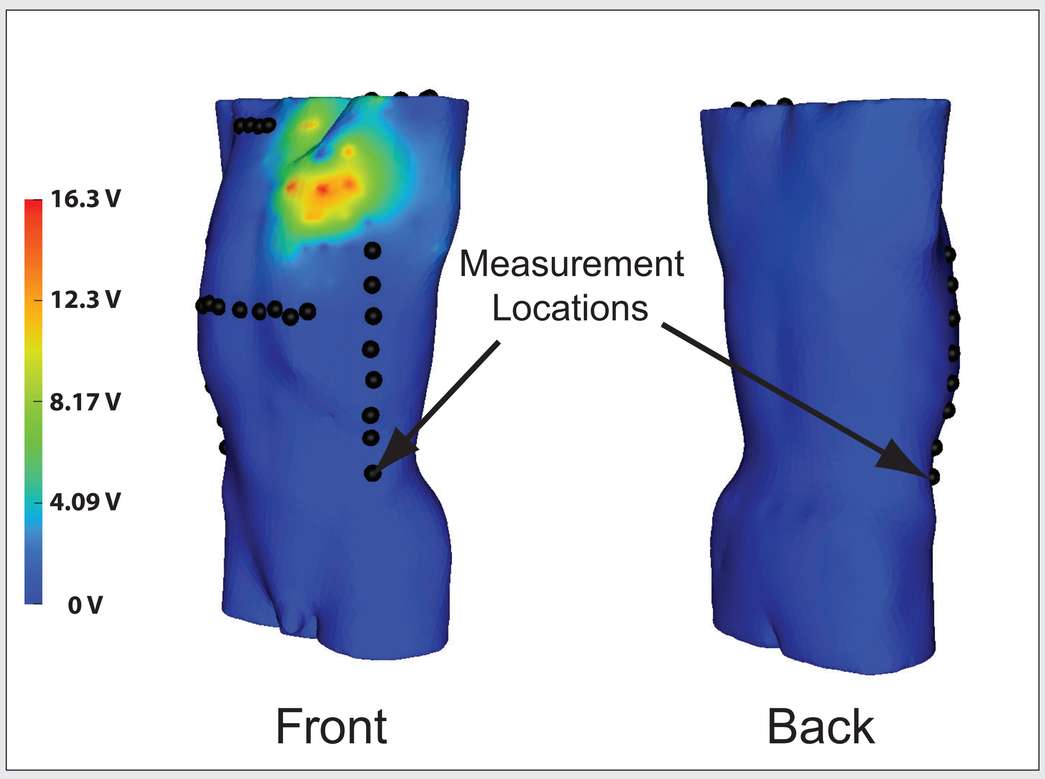


Figure 3. Typical difference map when body surface estimation performed on simulated surface potentials. High levels of error are located just inferior to the left clavicle where the device was placed. Potentials are based on an ICD shock of 500 V.

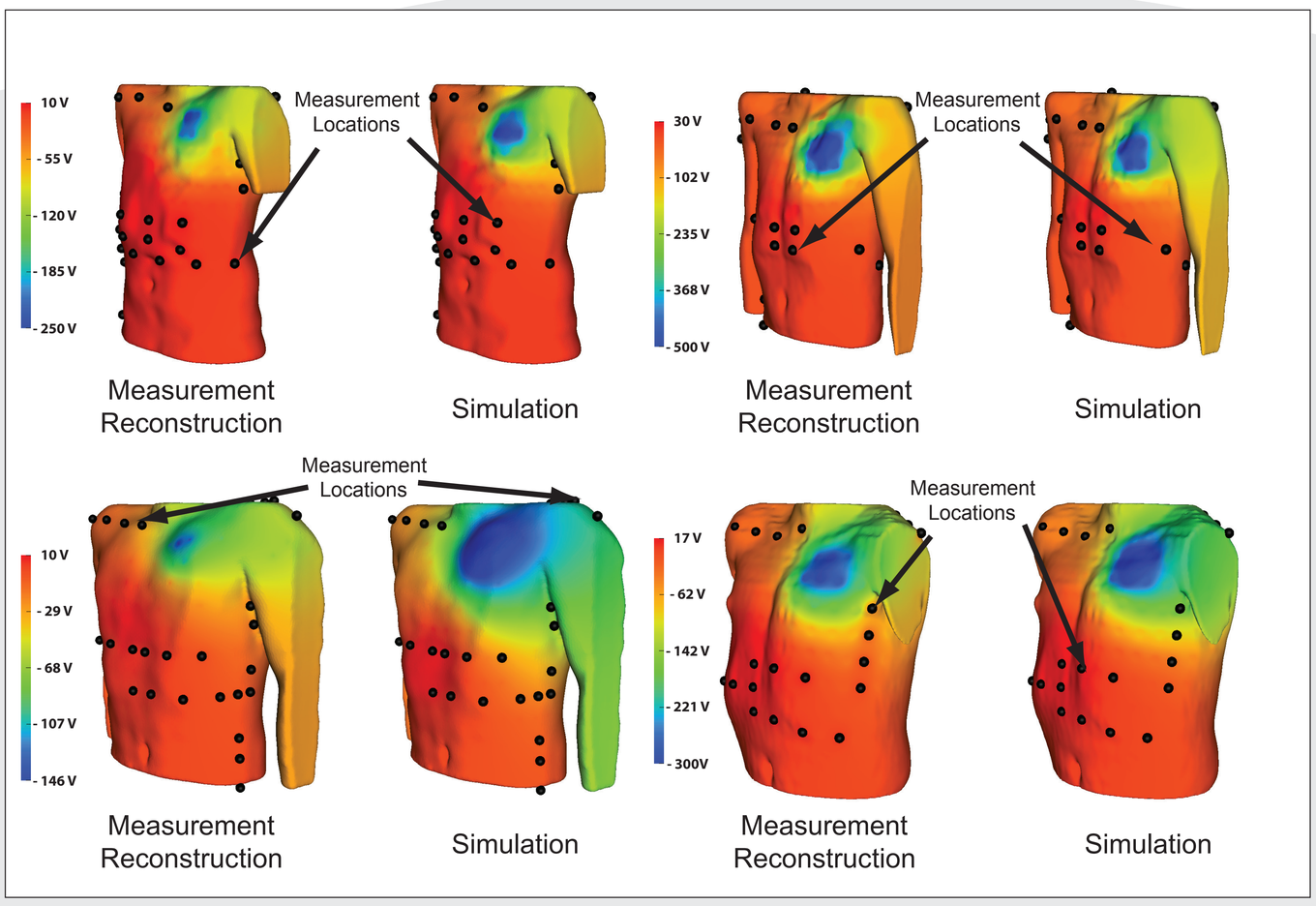


Figure 4. Examples of ICD surface potential estimation from surface recordings juxtaposed to the corresponding patent specific simulation of the surface recordings, one shock instance for four patients. The potential maps of the measurement reconstruction and the corresponding simulation are quantitatively similar, but noticeable differences are apparent near the device location (left shoulder). There was high quantitative similarities also with a mean correlation between surface potential maps of 0.966 and the relative error of 10.5 %.

Discussion

The data presented in Figures 3 & 4 demonstrate proof of concept of the body surface estimation algorithm in application to determining ICD surface potential distributions. This is apparent in the low levels of error in the simulation reconstructions (Figure 3) and shown to be possible with experimental data (Figure 4). The similarities in the measured and simulated potential maps also suggest an encouraging level of accuracy that provides a point of comparison to physiological data for the simulation.

Though the estimation from measurements and the simulation exhibit high correlation there are differences in the full potential map and especially in the potentials at the location of the measurements that cannot be rectified simply using a different conductivity scheme. This discrepancy suggests limitations in the computational model that need to be resolved. Previous studies suggest that altering the blood and the heart conductivities provides the biggest change in the predicted electric field [6], which are also observable on the surface. Because the electric field around the heart effects the torso potentials, it is probable that adding anisotropy in the myocardium may account for the difference in potential field [7]. Further improvements as incorporating an active model of the heart and a mono domain model of the rest of the torso tissue will increase the accuracy and realistic nature of the computational model.

References

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