MEASURING DEFIBRILLATOR SURFACE POTENTIALS FOR SIMULATION VERIFICATION

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Introduction

Implantable cardioverter defibrillators (ICD) are considered a mature technology, but they are not optimized for use in pediatrics or patients with abnormal geometries [1], nor are they optimized to prevent excessive energy output, which can cause unnecessary damage [2].

We have developed a simulation to predict the electric field during the discharge of the ICD and calculate the energy required for defibrillation, or defibrillation threshold (DFT) [3-5]. A study comparing DFTs observed clinically and predicted by the simulation, in addition to surface potentials generated by the simulation with actual body surface potential measurements during ICD discharge, is necessary to validate our simulation.

Our simulations are patient specific and we compared clinically recorded DFTs and ICD potential maps to the corresponding simulated values for a cohort of six patients. Standard clinical testing provided the DFT values for each case. Potential maps were measured using a 32 lead system optimized for recording ICD potentials by applying a limited lead selection algorithm [6].

Methods

Limited Lead Selection: To capture the entire body surface potential maps from a finite set of leads that also avoided the sterile field and defibrillation patches, we carried out a statistical estimation approach [6]. Training data from previous simulations provided the necessary information to derive a 32-lead system, which was tested using separate simulated test data (Figure 1).

Data Acquisition: Surface potentials using the 32-lead system and DFTs were acquired from four patients identified for ICD implantation and then compared to values predicted by the patient specific simulation (Figure 2). During the ICD testing, DFTs were found by sequentially increasing the shock energy until successful defibrillation, providing minimum and maximum bounds for the actual DFT.

Patient Specific Models: were generated for each patient from a full torso, high resolution MRI or CT obtained prior to the ICD implantation. Segmentation of relevant organs and tissues (Seg3D) and numerical mesh generation (SCIRun) provided the necessary geometric models. The ICD was then electronically placed in the torso model as indicated by post-operation X-rays. The simulation pipeline was performed on each patient (SCIRun) to predict the surface potentials and DFTs. The predicted surface potentials were compared to the measured potentials using the metrics correlation (ρ), relative error (RE), and relative RMS error ($\bar{E}$).

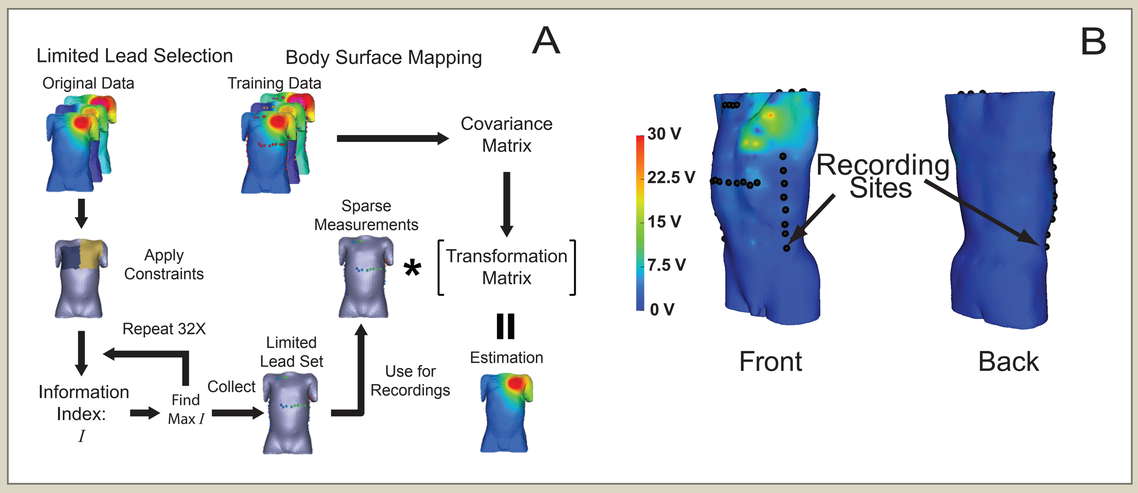
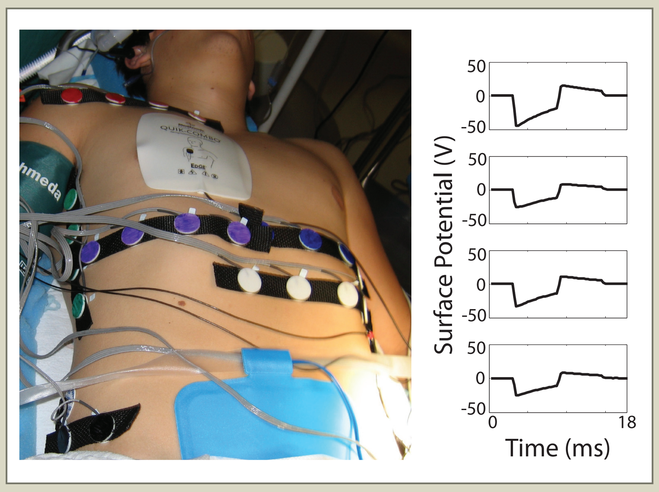


Figure 1. Limited lead selection algorithm implementation and typical error. A) Limited lead selection algorithm allows for full surface potential maps to be taken using only 32 lead locations [6]. B) Typical absolute error when simulated surface potentials are used as input into the optimized mapping system. Potentials are based on an ICD shock magnitude of 500 V.

Figure 2. Obtaining body-surface potentials. 32 Surface leads were placed at pre-determined locations. Sample recordings are also shown.



Results

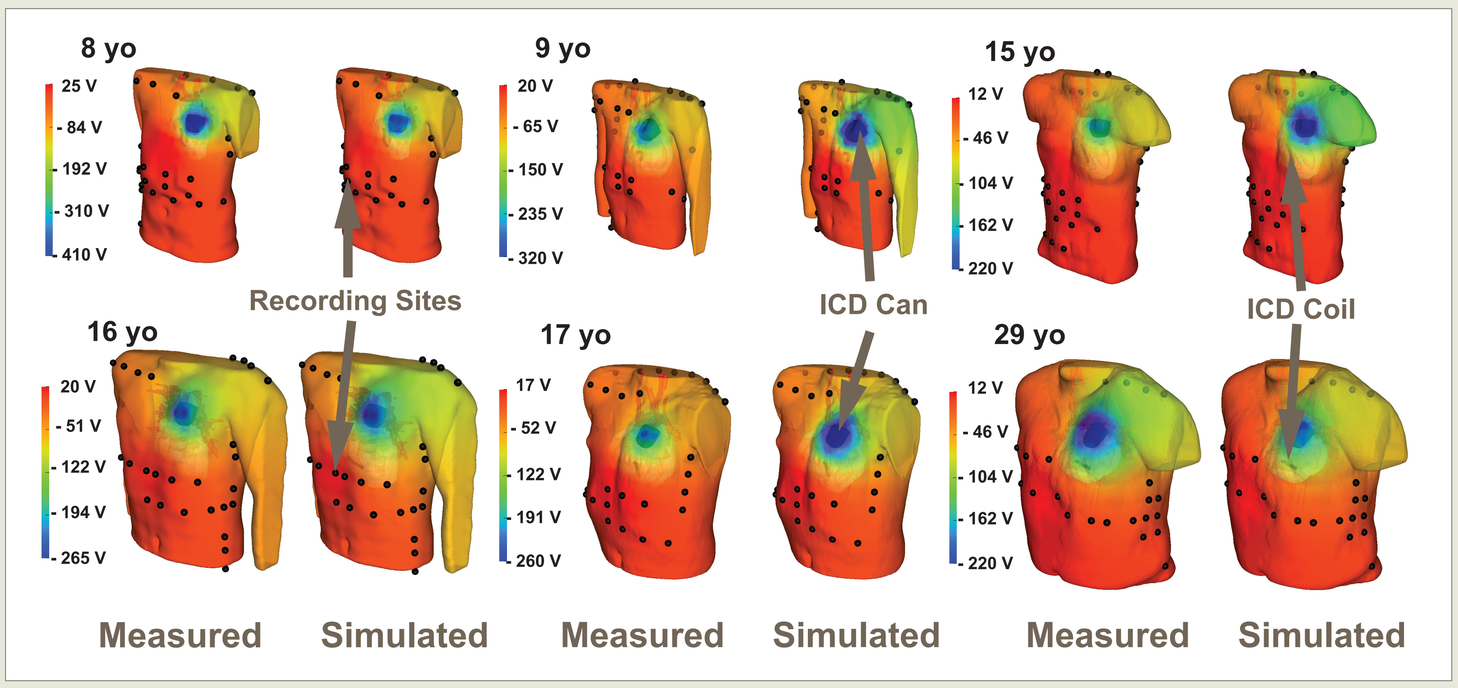


Figure 3. Comparisons of measured and simulated ICD discharge potentials. The six comparisons shown are sample shocks from each of the six patients, the age of each is indicated. ICD can and coil locations observed from post operative x-rays and used in the simulation are also shown.

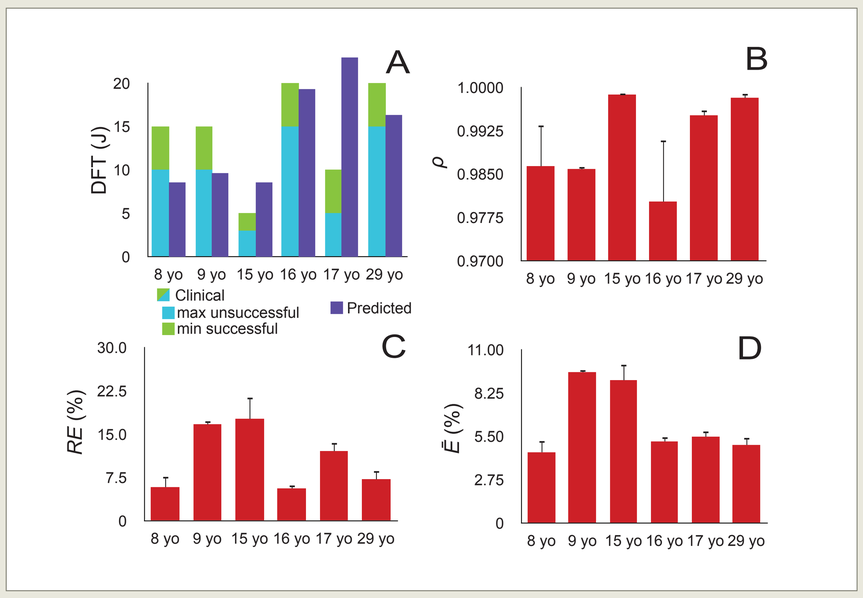


Figure 4. Comparison of DFTs and ICD discharge potentials recorded clinically and those predicted by the simulation. A) Clinically observed DFT ranges compared to values predicted by the simulation assuming 130 µF capacitance in the device. B-D) Mean metrics quantifying potential map comparison for each patient. Metrics used are correlation (ρ), relative error (RE), and relative RMS error ($\bar{E}$). Error bars indicate standard deviation for each metric and patient.

Discussion

The 32-lead body surface mapping system, customized for this application, proved to be suitable means of acquiring discharge potentials during ICD testing.

Validation studies indicated a generally high level of agreement between measured and simulated discharge potentials (Figures 3&4) with $\rho > 0.97$, $5 < RE < 22$ %, and $3.4 < \bar{E} < 10.2$ %, which adds confidence to the simulation and provides support for previous findings obtained using the pipeline [3-5].Though this validation study showed high overall accuracy, it also suggests areas for improvement.

Though there is high overall agreement between recorded and simulated potential maps, there are instances of high local error, which suggests possible improvements in the simulation. A previous study [7], as well as our preliminary explorations in conductivities suggests that small changes in the conductivity values, especially of the myocardium and blood, can significantly alter the potential distribution. Another source of error is the assumption of isotropic, passive conductivity of the heart, which ongoing studies seek to resolve [8].

Acknowledgements

This research is made possible with support from the Primary Children's Medical Center Foundation Grant, the NIH/NCRR Center for Integrative Biomedical Computing, 2P41 RR0112553-12, and the Cardiovascular Research and Training Institute. Support was also provided by Matthew Jolley from Stanford University, Dana Brooks from Northeastern University, and John Triedman from Children's Hospital Boston.

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