Measuring Implantable Cardio Defibrillators (ICDs) During Implantation Surgery to Verify a Simulation

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INTRODUCTION

ICDs are used to prevent fatal arrhythmias, and have become increasingly more common [1]. As the use of these devices is increased, so does the number of cases where standard implantation are not optimal for the patient, especially in children or persons with abnormal anatomies.

We have developed a simulation to predict the electric field during the discharge of the ICD and calculate the energy required for defibrillation. Verification of the simulation 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 [2], 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. Our goal in comparison is to determine the efficacy and the limitations of the measurement system and the simulation developed.

METHODS

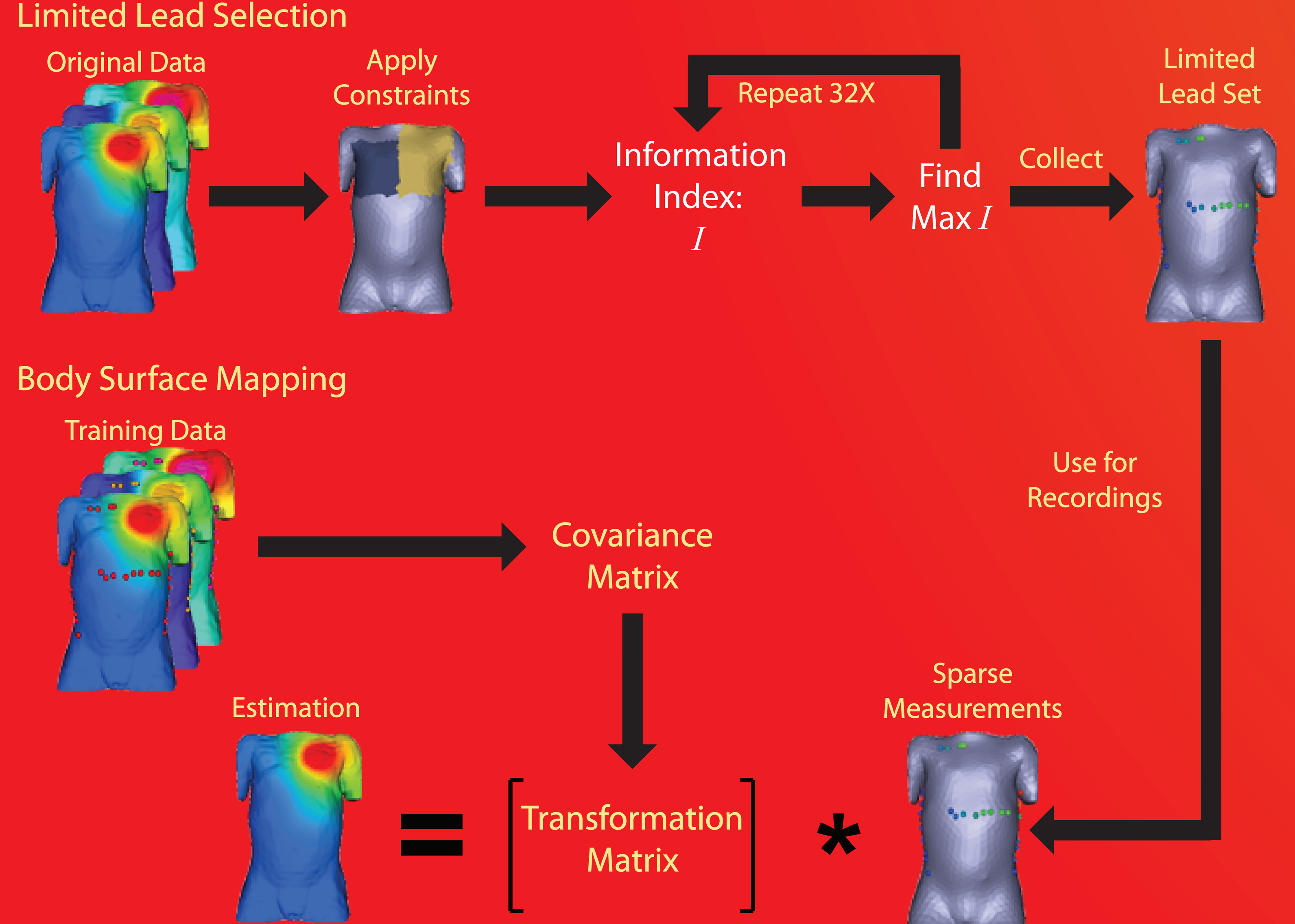

Figure 1. Limited Lead Selection and Body Surface Mapping. Body surface mapping is based on the statistical characteristics of a known set of torso potentials, specifically the covariance and standard deviation. With surface mapping, the full torso measurements can be taken using only 32 lead locations. 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. [2]

The application of the limited lead selection and full torso potential mapping offered significant challenges when used for ICDs during implantation surgery, the most substantial being the limited area available to take measurements. This challenge was overcome using the algorithm developed by Lux, et al. [2]. The algorithm determines the most important locations in estimating the surface potentials and establishes a statistical relationship between these points and the rest of the torso. Using simulated surface potentials we calculated the optimal lead locations and developed a transformation matrix to reconstructed the surface potentials (Figure 1). Reconstructions were performed on a separate set of simulations for accuracy.

A comparison was then made between a patient specific simulation and the corresponding surface recordings. The simulation was made for the patient using MRI scan data obtained a week prior to implantation. Surface potentials were recorded during the implantation surgery and reconstructed using the calculated transformation matrix. The measurements and the simulation were compared to determine the accuracy of the simulation.

RESULTS

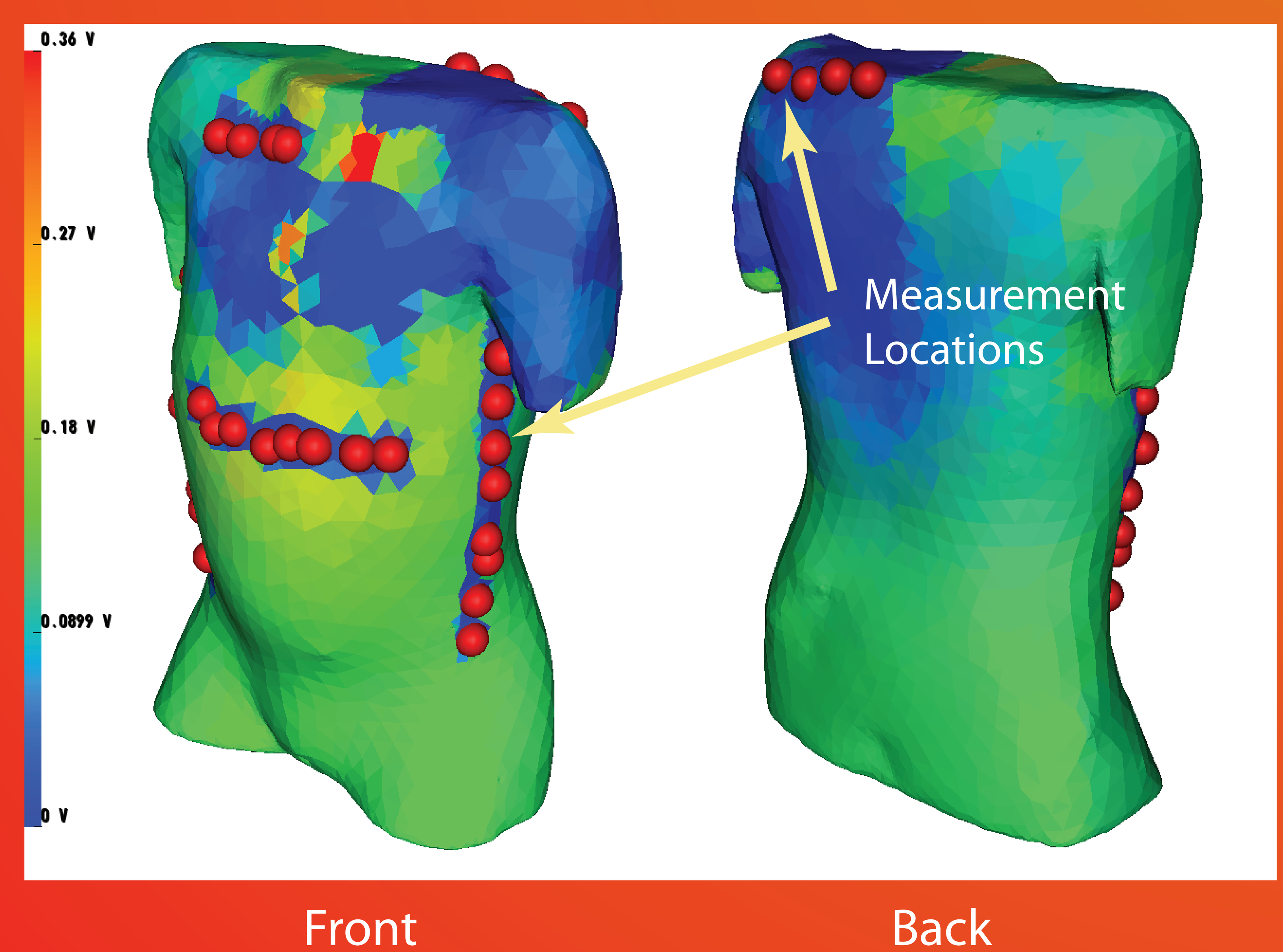

Figure 2. Absolute difference in the reconstruction of the simulated test data set. As indicated, there are areas of low error near the measurement locations and on the superior left region. The error near the ICD in general has low error, but the highest error is in this region also. The majority of the torso contains mid range error, but the highest error in this reconstruction is still below 1 V. The ICD source voltage was set to 500 V in the simulation. The simulated potentials on the surface were above 150 V at any point on the torso, making percentage error is less 1 % at any location.

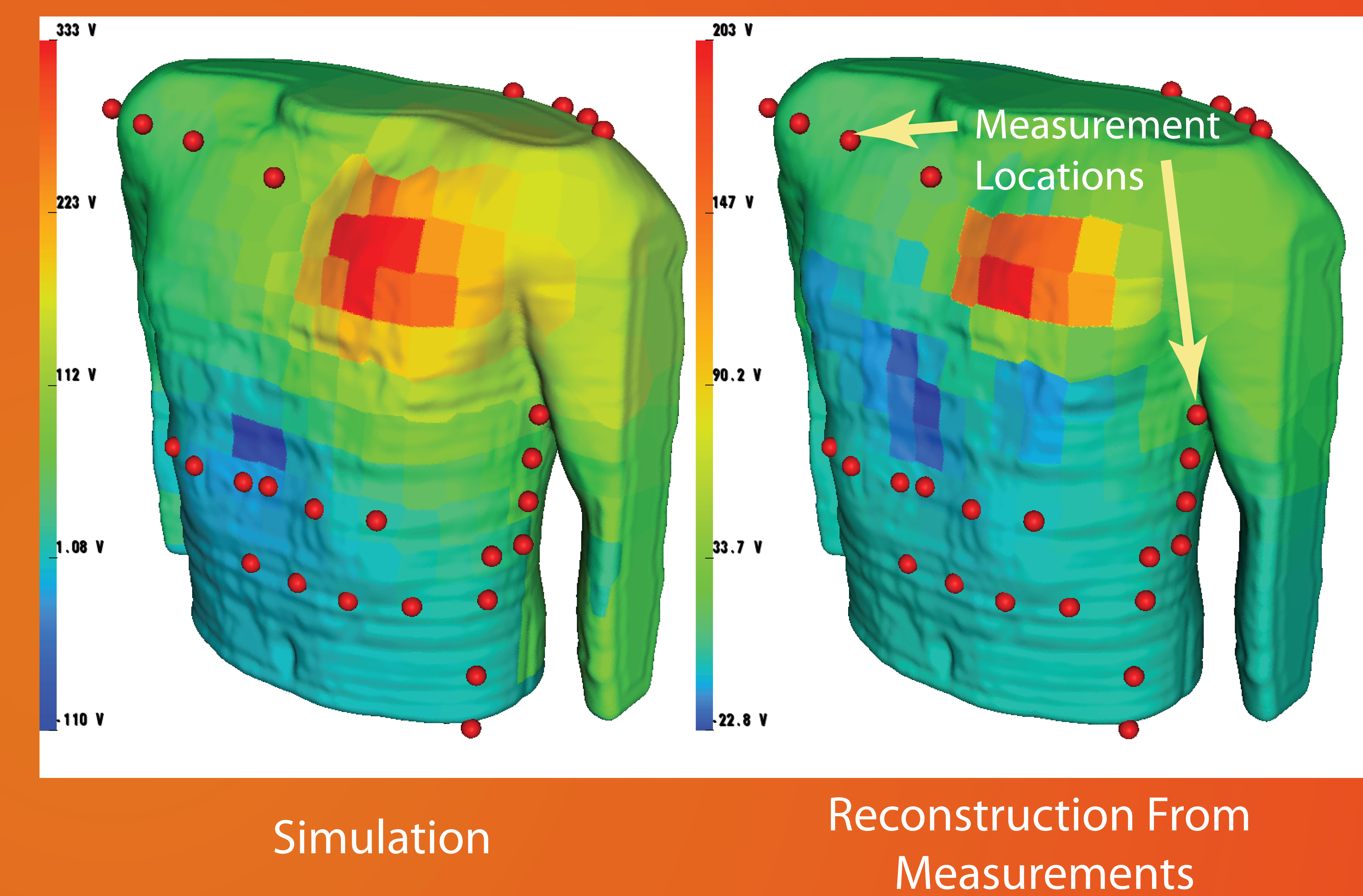

Figure 3. Comparison between the patient specific simulation and the reconstructed potentials estimated from surface recordings. Though the magnitude of the surface potentials are different, the patterns are similar (correlation of .81). The magnitude of the recordings (locations indicated in red) were different from the simulation by a factor of three, but the profile of the potentials were also very similar.

CONCLUSION

The reconstruction algorithm used to the surface potentials of ICD discharges is effective in accurately representing the full torso potentials. The effectiveness of the algorithm is demonstrated the accurate reconstruction of the simulated test set surface potentials (Figure 2) and the high correlation of the reconstructed measurement potentials (Figure 3).

Because the surface recordings and the reconstruction generated from them were so different form the simulated potentials at corresponding locations, there may be a problem with one or more of the assumptions that are made in the simulation. The similarity of the profiles and the high correlation indicate that the missing complexity likely involves a linear factor that is involve such as conductivity differences.

The measurement technique developed with the optimal lead set shows promising accuracy in representing the ICD potential field. Though the simulation may need refinement, this method has indicated that the simulation expresses the correct profile of the ICD discharge.

References

[1] M. Alexander, F. Cecchin, E. Walsh et al. , "Implications of implantable cardioverter defibrillator therapy in congenital heart disease and pediatrics," J Cardiovasc Electrophysiol, vol. 15, pp. 72-76, 2004.

[2] R. L. Lux, C. R. Smith, R. F. Wyatt et al. , "Limited Lead Selection for Estimation of Body Surface Potential Maps in Electrocardiography," IEEE Transactions on Biomedical Engineering, vol. BME-25, No. 3, no. May 1978, pp. 270-276, 1978.