DefibSim: An Interactive Defibrillation Device Design Tool

John A. Schmidt Christopher R. Johnson
Department of Computer Science
University of Utah
Salt Lake City, Utah 84112, U.S.A.
jas@cs.utah.edu and crj@cs.utah.edu

Abstract

We have developed an interactive computer modeling tool (**DefibSim**) for defibrillation device design. This system allows researchers to interactively design and place electrodes within a large-scale thorax model and then compute the electric and potential fields using an adaptive finite element method. Both visual and quantitative measures have been developed to determine the efficacy of different electrode configurations. This tool has allowed us to quickly and efficiently investigate over 170 different electrode configurations. A promising subset of electrode locations are now being tested in animals as well as in clinical environments.

Introduction

Fibrillation, which may be described as abberrant heart rhythms, can often be terminated by the application of large electrical shocks delivered to the heart–the process of defibrillation. The design and placement of defibrillation electrodes is a critical component for effectively restoring normal rhythm. Significant heart damage can occur if large currents are injected from poorly designed and improperly placed electrodes. Initially, the design and placement of these electrodes involved a trial and error process conducted in animal studies to determine near optimal configurations. More recently, computer models based on animal and human anatomy have attempted to assist in the design and placement of electrode configurations. However, these computer models were difficult to construct and previously available software tools were not designed for large-scale biomedical device design [1]. To circumvent the difficulties that exist in current defibrillation computer modeling systems, **DefibSim** was developed to integrate the software tools used in the design, placement, and analysis of different electrode configurations. The interactive nature of the electrode design and placement and the built in model generation capabilities has provided us with a tool that can be used to rapidly test a large number of possible electrode designs and configurations reserving the most promising candidates for animal studies.

Model Construction and Electrode Design

MRI scans were digitized to provide the boundary points defining the major electrically relevant conducting regions that comprise the Utah Torso Model [2, 3]. These include subcutaneous fat, skeletal muscle, lungs, ribs (clavicle and sternum), epicardium, epicardial fat pads, blood cavities (atria and ventricles), and the major blood vessels (pulmonary artery and vein, aorta, superior and inferior vena cava, subclavian, innominate and azygous veins). A cutaway figure of the model highlighting the different anatomical regions is shown in figure 1.

The electrodes consisted of rectangular subcutaneous patch electrodes and cylindrical internal electrodes. Interactive deformation of the electrodes was performed to ensure that the subcutaneous electrodes conformed to the ribs and that the internal electrodes would fit inside the major vessels. Following the deformation and placement of the electrodes, a volume mesh was automatically created consisting of approximately 1.5 million elements (250,000 nodes) [1]. Dirichlet boundary conditions were then assigned to the electrode surfaces. Over 170 different electrode combinations were evaluated which required the construction of 50 different volumetric meshes. The finite element method was used to solve for the potential and current density distributions. Analysis of the efficacy was determined via a graphical display of results incorporated into **DefibSim** and by the defibrillation criteria outlined below.

Defibrillation Criteria

Five different defibrillation criteria were used to determine the efficacy of electrode configurations. These included *electrode voltage threshold (EVT)*, *efficiency (Eff)*, *damage*, *uniformity (Unif)*, and *lead impedance* Z_L. EVT was defined as the voltage difference across the electrodes necessary to yield a gradient of either 5 V/cm, (monophasic shocks) or 3.5 V/cm, (biphasic shocks) in 95% of the heart tissue. The **efficiency** of the delivered shock was based on the ratio of the energy reaching the heart to the total energy delivered. The **damage** level was determined to be the percentage of heart tissue above a particular gradient level. The gradient level used for monophasic shocks was 50 V/cm and 70 V/cm for biphasic shocks. The **uniformity** of the delivered shock was based on the

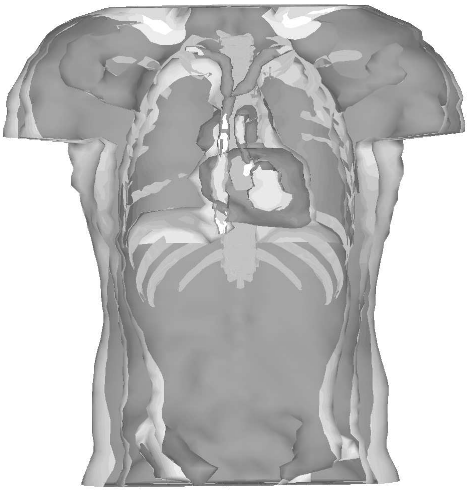

Figure 1: Cutaway of the Utah Torso Model showing the different anatomical regions included in the model.

ratio of the peak electric field in the heart volume to the average electric field in the heart volume. It ranges from 1 for a perfectly uniform field to ∞ for a non-uniform electric field. The **lead impedance** is the impedance across the electrodes and is commonly determined in actual experimental and clinical settings such that it serves as an additional validation of the model.

Results

Over 170 different electrode combinations were implemented and computationally tested with **DefibSim**. Preliminary results demonstrated that several of the defibrillation criteria parameters were within the ranges measured in clinical and experimental settings. Shown in Figure 2 is the current density distribution on the heart surface for a particular defibrillation electrode configuration. The darker regions indicate high current density magnitudes.

Table 1 compares two different electrode configurations that we explored. The first case refers to two cylindrical leads positioned in a vessel and blood cavity. The second case refers to the same lead system with an additional anodal subcutaneous patch. Case 2 with a subcutaneous patch has a significantly lower threshold voltage compared to case 1. Based on the criteria that smaller electrode voltage thresholds are better, case 2 could possibly merit further testing.

Conclusions

We have developed and tested **DefibSim**, a new software tool simulating defibrillation in humans. It has proven useful in efficiently evaluating a large number of different electrode configurations. Results of these simulation studies have suggested possible electrode combinations that are now being investigated in animal studies to further confirm the model.

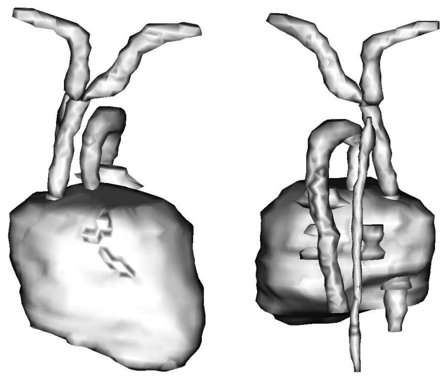

Figure 2: Figure showing the current density magnitude distributions for both the anterior and posterior views of the mediastinum for a typical defibrillation configuration.

	EVT			Damage			
	Mono	Bi	Eff	Mono	Bi	Unif	Z_L
1	801.8	561.3	18.7	14.3	3.0	14.0	48.5
2	389.7	272.8	17.2	3.5	0.02	7.8	34.6

Table 1: A sample comparison of the defibrillation criteria results for two different cases. Case 1 is for an anode and cathode lead system. Case 2 uses the same lead system as case 1, but it also includes an anodal subcutaneous patch electrode.

Acknowledgments

This work was supported in part by awards from Pacesetter, Inc, the NIH, the NSF, the NCSA, and the DOE. Special thanks to R. Klepfer for modeling assistance.

References

[1] J. Schmidt. *Mesh generation with applications in computational electrophysiology.* PhD thesis, Duke University, Durham, NC, 1993.

[2] C.R. Johnson, R.S. MacLeod, and P.R. Ershler. A computer model for the study of electrical current flow in the human thorax. *Computers in Biology and Medicine*, 22(3):305–323, 1992.

[3] C.R. Johnson, R.S. MacLeod, and M.A. Matheson. Computational medicine: Bioelectric field problems. *IEEE COMPUTER*, pages 59–67, Oct., 1993.