Partially Extracted Defibrillator Coils and Pacing Leads Alter Defibrillation Thresholds

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Summary: Abandoned ICD coils and pacing leads provide a conductor substrate for electric field perturbations during cardiac defibrillation (DF). A full torso MRI was used to create finite element computer models (FEMs) to simulate DF in 112 FEMs. Electrostatic DF simulations were performed with and without abandoned defibrillator leads. Abandoned undamaged ICD coils did not change DFTs (-0.91 to 0.46 J, mean change 0.01 ± 0.27, p=0.76). Abandoned epicardial coils slightly changed DFTs (-1.7 to 6.73 J, mean change 1.5 ± 2.5, p=0.04). Abandoned damaged ICD coils increased DFTs in most cases (57) but slightly decreased DFTs in 5 (-0.69 to 27.28, mean 6.24 ± 7.26, p<0.001). FEMs predict damaged partially extracted ICD coils and pacing leads can alter DFTs, but intact abandoned ICD coils and pacing leads have little effect on DFTs.

Introduction: Sudden cardiac death is the leading cause of death in the United States with 325,000 deaths per year. This translates to 1,000 deaths per day or 1 death every two minutes.[1] Implantable cardioverter defibrillators (ICD) were developed to provide immediate treatment to patients identified as being at-risk for sudden cardiac death and remain the only mechanism available to treat ventricular fibrillation and unstable ventricular tachycardia within seconds of onset. With the increased utilization of ICDs clinical situations such as lead fracture are arising that involve ICD leads that are no longer useful. In these situations the lead will either be extracted[2] or abandoned and a new ICD lead will be placed. If the leads are partially extracted or abandoned they provide a conductor substrate that will cause electric field perturbations during cardiac defibrillation[3]. In this study we use a previously described computer simulation of cardiac defibrillation[4-6] to quantify the change in defibrillation threshold caused by abandoned ICD coils and pacemaker leads.

Methods: A full torso thin slice MRI was performed prior to ICD implant in a 14 year old with hypertrophic cardiomyopathy. The MRI was segmented into ten tissue types using Seg3D Figure 1. Each tissue type was assigned its respective conductivity Table 1. Full torso finite element models (FEM) were created in SCIRun. ICD generator, ICD leads and abandoned ICD coils and pacemaker leads were interactively placed into 112 unique FEMs using SCIRun Figure 2. Abandoned leads were varied between intact ICD coils, damaged ICD coils and damaged exposed metal pacing leads. Damaged ICD coils were modeled to have an increase in exposed metal or an electrical short between coils in a dual coil lead. Lead positions were systematically varied. Electrostatic defibrillation simulations were performed with and without abandoned leads. The critical mass hypothesis requiring 95% if the ventricular myocardium to reach an electric potential of 5V/cm was used to calculate DFTs[7]. The change in DFT from defibrillation without the abandoned lead to defibrillation with the abandoned lead was used for analysis.

Results: Results are reported as the change in DFT in joules from defibrillation simulation without abandoned leads to the DFT with abandoned leads. Type 1 error of 0.05 was used to determine statistical significance. Table 2 provides a summary of the results. Figure 3 shows the electric potential isosurfaces coded according to amplitude and illustrates a case in which a large predicted change in DFT was obtained. Abandoned undamaged ICD coils did not change DFTs (-0.91 to 0.46 J, mean change 0.01 ± 0.27, p=0.76). Abandoned epicardial coils slightly changed DFTs (-1.7 to 6.73 J, mean change 1.5 ± 2.5, p=0.04). Abandoned damaged ICD coils increased DFTs in most cases (57) but slightly decreased DFTs in 5 (-0.69 to 27.28, mean 6.24 ± 7.26, p<0.001). FEMs predict damaged partially extracted ICD coils and pacing leads can alter DFTs, but intact abandoned ICD coils and pacing leads have little effect on DFTs. Increased DFTs directly correlated to length of exposed metal (R 0.81). The DFT predicted by our FEM using the patient's ICD generator and lead positions (21.29 J), closely approximated the clinical DFT measured at implant (20 J).

Limitations: In this study we assume an electrostatic solution of the electromagnetic field created during defibrillation. We also use the critical mass hypothesis of 95% of the ventricular myocardium reaching 5 V/cm to calculate the defibrillation threshold. While the critical mass hypothesis likely is a sufficient condition for defibrillation it may not be a necessary condition. Electrical conductivities are assumed constant rather than frequency dependent and each tissue type is assumed isotropic.

Conclusions: Finite element models predict intact abandoned ICD coils and pacing leads have little effect on DFTs. FEMs predict that abandoned partially extracted ICD coils and pacing leads with increased exposed metal can alter DFTs. This study also showed that full torso MRI based FEMs can predict clinical DFTs with high accuracy.

References:

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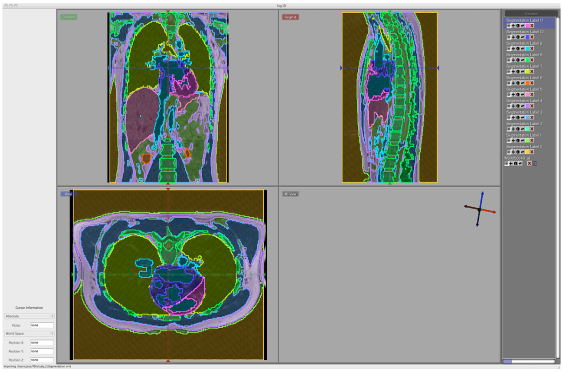

Figure 1: MRI segmentation. MRI segmented into 10 tissue types using Seg3D

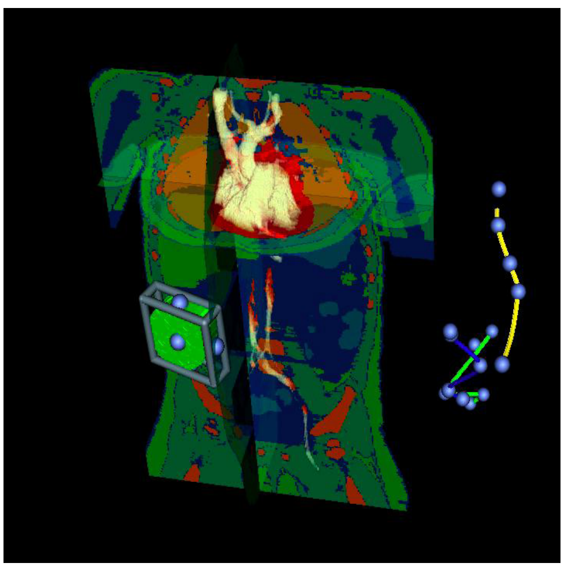

Figure 2: Interactive lead placement. The image shows a segmented torso with the ICD generator in the right abdominal wall and leads yet to be placed off to the right of the torso.

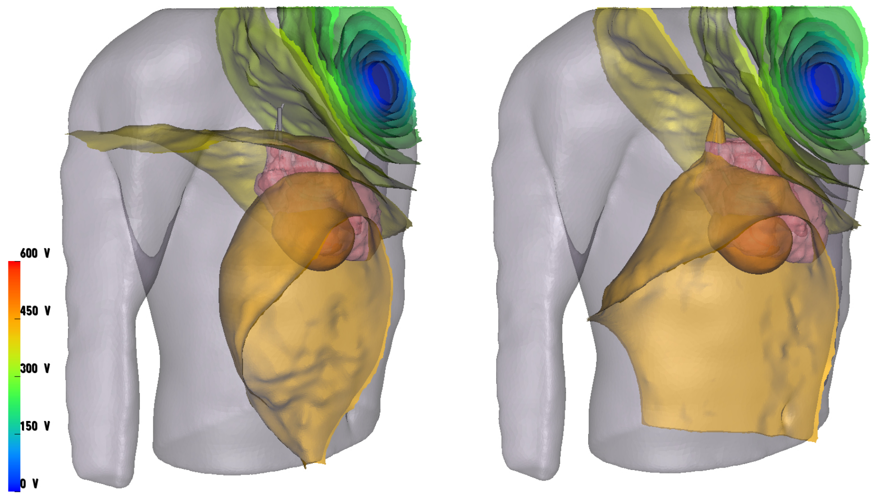

Figure 3: Simulation results. The torso on the left shows the electric potential isosurfaces coded according to amplitude during a simulated defibrillation using a left chest generator and right ventricular apex coil. The torso on the right shows the results for the same generator and coil with the addition of an abandoned dual coil lead. Note the overall change in isopotentials, especially those of large amplitude near the heart. The isopotentials tended to wrap around the abandoned SVC coil, confirming that it is at constant electric potential.

Connective Tissue	0.22
Bowel Gas	0.002
Skeletal Muscle	0.25
Fat	0.05
Kidney	0.15
Liver	0.07
Lung	0.007
Bone	0.006
Blood	0.7
Heart Muscle	0.3

Table 1: Tissue types with corresponding electrical conductivity (S/m)

Abandoned Lead type	**Change in DFT (Joules)**	**Mean change in DFT (Joules) ± SD**	**Ratio of DFT with abandoned lead/without abandoned lead**
Intact abandoned ICD coils	**-0.91 – 0.46**	**0.01 ± 0.27, p=0.76**	**0.98 - 1.10 (mean 1±0.01)**
Intact abandoned epicardial ICD coils	**-1.7 – 6.73**	**1.50 ± 2.50 p=0.04**	**1.01 – 1.05 (mean 1.02±0.02)**
Damaged abandoned ICD coils and pacing leads	**-0.69 – 27.28**	**6.24 ± 7.26, p<0.001**	**0.97 – 2.21 (mean 1.25±0.28)**

Table 2: Summary of results