Collaboration: John Triedman and Matt Jolley

Patient Specific Simulation of Defibrillation in Children

Collaborators:

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  Dana Brooks, Professor of ECE, NEU

CVRTI/SCI Institute:
  Jeroen Stinstra, Staff Scientist

Brigham and Women’s Hospital
  C.F. Westin
  Kilian Pohl
  Steve Pieper
  Gordon Kindlmann
Implantable Cardiac Defibrillators (ICD)

68,000 adult cases annually in the US (2004)

Standard Transvenous ICD
Ad Hoc Configurations in Children

Problem

- Small but important population
- Highly variable size and anatomy
- Little validation of techniques
- Currently requires ad hoc orientations
- New subcutaneous configurations as yet untested
Objectives

Clinical
- Determine optimal ICD electrode placements
- Apply in patient specific manner

Engineering
- Create subject specific finite element models
- Evaluate metrics for electrode positioning
  - Myocardial voltage gradients
  - Defibrillation thresholds

Approach

1) Bioelectric Fields
2) Computer Simulation
3) Medical Imaging
4) Scientific Visualization
5) Clinical Verification and Validation
1) Bioelectric Fields

Intrinsic

Extrinsic

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SA Node

Atria

AV Node

Bundle of HIS

Purkinje Fiber

Ventricles

-Time (ms)

10

5 mV

0

0

500

Mathematics represents underlying mechanisms (Laplace’s equation)

Computer provides solutions to mathematics (Finite Element Method)

Allows “what if” testing of scenarios

Requires validation through experiments
FEM in Defibrillation

- Well documented in defib literature
  - Jorgenson et al, 1995
  - Dejongh et al, 1999
  - Aguel et al, 1999
  - Mocanu et al, 2001, 2004
- Reasonable validation in adults
- For children must be patient specific
- Current methods laborious and inaccessible to clinical providers

3) Medical imaging

- Contains patient specific information
- Provides source for computer models of geometry
4) Scientific Visualization

5) Clinical Validation & Verification

- Sanity check of simulation results
- Comparison with literature results
- Dedicated experiments
Technical Steps

1) Medical Imaging
2) Segmentation
3) Mesh generation
4) Placement of electrodes
5) Computation
6) Visualization

1) Medical Imaging

Whole-torso CT scans
- Trauma center scans (50)
- Focus on 3 cases, aged 2, 10, and 29
2) Segmentation

3) Meshing and Local Remeshing
4) Placement of Electrodes

Solving Laplace’s equations

Compute Electric Field in Myocardial Volume

5) Computation

Extract Metrics of Effectiveness

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6) Visualization

• Voltage gradients, current densities, surface voltages
• Defibrillation effectiveness/thresholds
• Influence of model parameters

Voltage Gradient
Myocardial Voltage Gradients

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98.54% > 5 V/cm for 500V shock
4.17% > 30 V/cm for 500V shock

Single Case Summary

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Small Changes → Large Effect

Patient Specific Implementation
### Patient Specific Implementation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Predicted DFT (J)</th>
<th>Clinical DFT (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPC + right EPI → left EPI (A)</td>
<td>66.2</td>
<td>Not Tested</td>
</tr>
<tr>
<td>LPC → left EPI + right EPI (B)</td>
<td>118.9</td>
<td>Not Tested</td>
</tr>
<tr>
<td>LPC + left EPI → right EPI (C)</td>
<td>24.0</td>
<td>15-20J</td>
</tr>
<tr>
<td>Inactive Can: left EPI → right EPI (Not shown)</td>
<td>47.5</td>
<td>&gt; 35J</td>
</tr>
</tbody>
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### Defibrillation Modeling Plans

- Use Seg3D for segmentation
- Improved mesh generation
- Validation of defib results
- Utah Hearts

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Utah Hearts