Quantitative Electrocardiography: Two Steps Forward and One Step Back

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The Credits
Goals of Quantitative Electrocardiography

Understand mechanisms $\Rightarrow$ Forward Models

Validate models $\Rightarrow$ Inverse Problems

Improve diagnostics $\Rightarrow$
The Motivation

Driving Themes

Technical
- Forward models: myocardial tissue to whole heart
- Signal processing: catheter based cardiac mapping
- Inverse solutions: multiconstrained approaches
- Software: making it all work

Biomedical
- Tissue function: coupling and anisotropy
- Organ Pathology: ischemia, arrhythmias
- Molecular biology: mutations/transgenics
Forward Models: the Bidomain Method

- 2 domains share the same space
- Membrane separates the domains
- All properties (e.g. $V_{ec}$, $r_{ec}$) are macroscopic averages

Bidomain Parameters

- $\sigma_{et}$, $\sigma_{el}$, $\sigma_{it}$, $\sigma_{il}$
- Tissue conductivity
- Diffusion-weighted MRI (direction)

Modeling Conductivity

Building block: hexagon

Cluster of 27 myocytes


Mouse Heart Models

- MRI input data
- Segmented ventricles
- 225,236 hex elements

Craig Henriquez, Duke University
Mouse Activation Sequence

Activation

Recovery (-60 mV)

APD

SCI __________________________ CVRTI

0.5 ms
6.5 ms
8.5 ms
10.5 ms

Forward Computation of ECG

SCI __________________________ CVRTI
Modeling Ischemia

St-segment elevation

Biophysics of Acute Ischemia

Intracellular current
Geometric Model

Ischemic Zone

RV
LV

Validation: Experimental Preparation

Pump
Electrodes

Hopenfeld et al. JCE, 15:1200, 2004

Shome et al. IEEE EMBS, 2004
Extent of Ischemia

Experiments
- 50% flow
- 25% flow
- 1% flow

Simulations
- 40% transmural
- 70% transmural
- 90% transmural

Ischemic Zone

Signal Processing:
Detection of Arrhythmias

Cardiac Mapping
- Body surface
  - 12-lead ECG
- Direct
  - BSPM
- Catheter-based
  - Epicardial
  - Endocardial
Overcoming Limited Resolution

Sparse catheter measurements — Signal processing — High-resolution Activation maps

Signal Processing

- How do we determine the relationships between known and unknown sites?
  - Interpolation
    - global pre-assumptions
  - Estimation
    - create these assumptions from a previously acquired set of data (training data)
Estimation Results

Original | AME | AME-Spat Act | AME-Temp Act

Inverse Solutions by Multiple Constraints

Forward

Inverse

SCI --- CVRTI
Combing Information Sources

Sparse Epicardial Measurements (SEP)

Torso measurements and forward model (TOR)

Training dataset of epicardial maps (TS)

\[ x = \begin{bmatrix} x_m \\ x_u \end{bmatrix} \]

Solution Approaches

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<th>Information Source</th>
<th>Tikhonov</th>
<th>Tikhonov - ED</th>
<th>MAP</th>
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Potential maps

original

tikh

tikh-ED

epi est

map

map-ED

Error std

epi est

map

map-ED

Potential maps

Serinagaoglu et al. IEEE T-BME, 2005

Solution Approaches

TS

SEP

TOR

Tikhonov

Tikhonov - ED

MAP

MAP - ED

Epi. Est.

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<th>Method</th>
<th>Smoothed</th>
<th>Stable but missing focus</th>
<th>Good compromise, less noise</th>
<th>Good focus</th>
<th>Noisy, false extrema</th>
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The Software: Requirements (Wish List)

- Flexible
- Portable
- Integrated
- Extensible
- Powerful
- Efficient
- Easy to learn
- Cheap (aka free)

- MATLAB
  - Brainstorm
  - MatMap
  - Utility code
- SCIRun/BioPSE
- map3d
- Cardiowave
- ECGSim
- NeuroFEM/Vgrid

Pillars of SCIRun

- Accessibility
- Integration
- Reusability
One Step Back

- What is the role of tissue structure?
  - gap junctions
  - discrete vs. continuous models
- How can we use ischemia models?
  - body surface information
  - effects on propagation
- What do cardiac maps tell us?
  - covariance matrix
  - detection of arrhythmias
- What are relevant inverse constraints?
  - identification
  - parameterization
- How do we span scales?
  - multiscale modeling
  - inclusion of molecular biology information