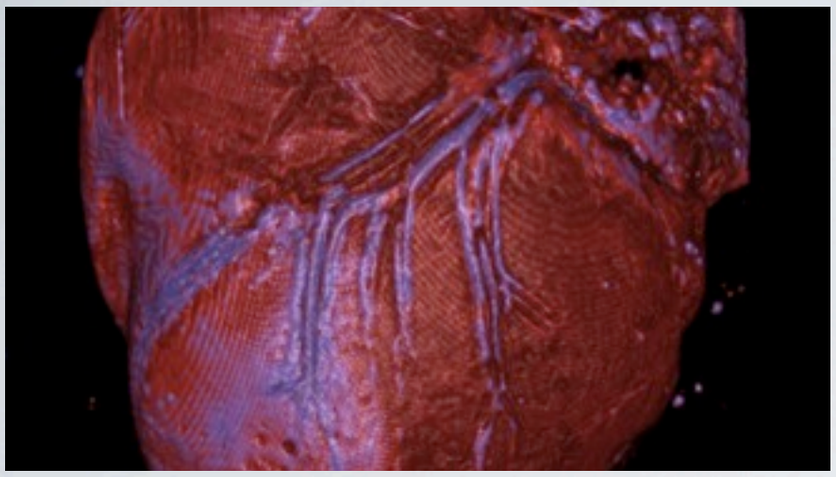
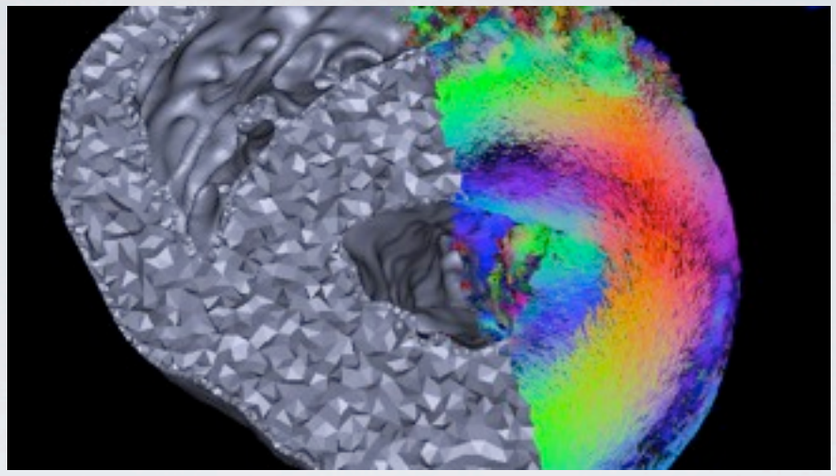
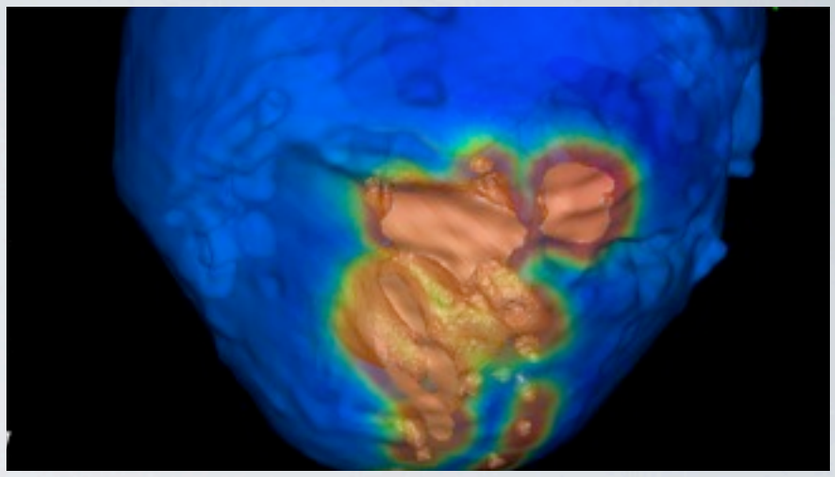
2009 PHD COMMITTEE MEETING

Darrell Swenson
Rob MacLeod, Jeroen Stinstra, Chris Johnson, Ed Hsu

LONG TERM VISION

To develop the skills and knowledge base that will allow me to develop patient specific models that can be used to diagnose and treat patients in a clinical setting. These skills include but are not limited to, understanding of physiological processes, image acquisition, image processing, model creation, simulation, and interpretation of results.

COURSES

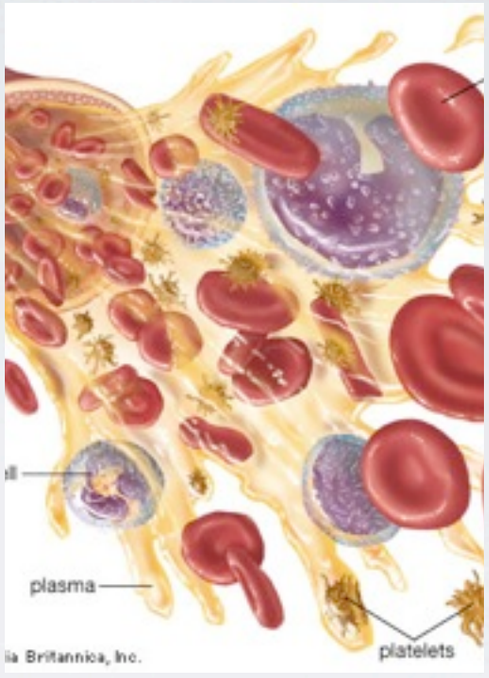
Undergraduate: Mechanical Engineering - Emphasis in CAx tool integration

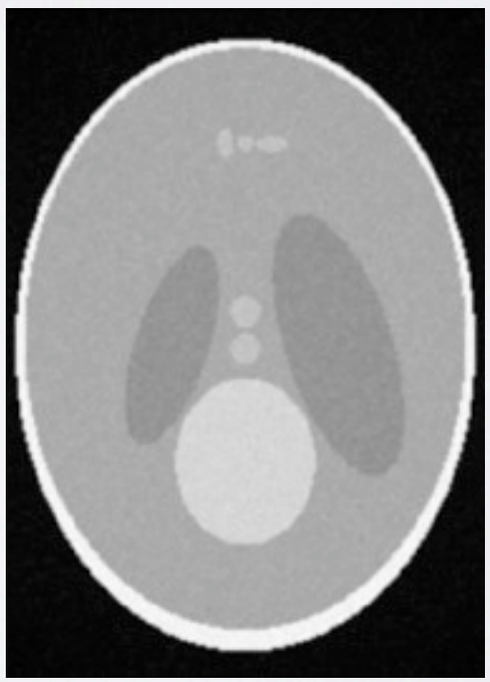
Graduate Courses: Credits 32

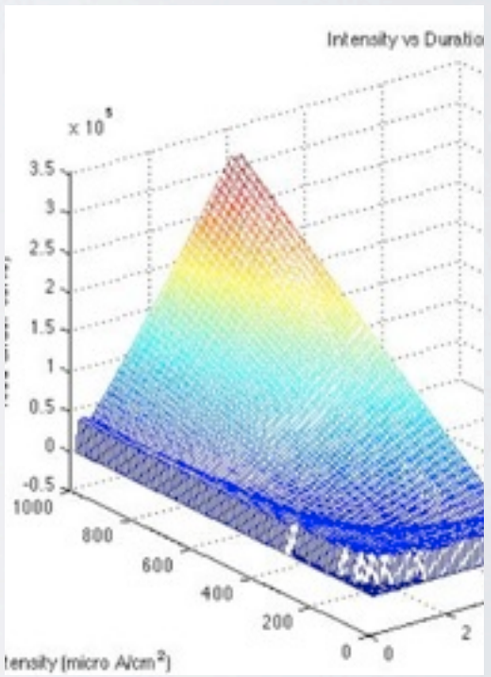
BIOEN 5091 Current Research
BIOEN 5401 Medical Imaging Sys
BIOEN 6050 Cellular Physiol
BIOEN 6060 Scientific Presentations 1 & 2
BIOEN 6102 BioInstrumentation
BIOEN 6000 Systems Physiology 1
BIOEN 6102 Molecular Biophysics
BIOEN 6640 Image Processing
BIOEN 6003 Cellular Biophysics
BIOEN 6464 Cardiac EP Seminar
CS 6210 Adv. Sci Computing 1 & 2

Graduate Future Courses: CES Certificate

BIOEN 6460 Bioelectricity
CS 6630 Scientific Visualization
CS Computational Geometry
Math 5740 Mathematical Modeling
Math 6790 Case Studies







TIME LINE

2009

June: Form Committee
July: Ischemia Experiments
Sept: Conference Presentations
Oct: Take Qualifying Exam
Dec: Research Proposal

2010

April: Submit Paper - Ischemia Border Zones
Summer: Ischemia Experiments
Nov: Submit Paper - Meshing Along FIber Sheets

2011

Jan: Begin Thesis
Feb: Submit Paper - Helical Angle Variation in Bidomain Models
Summer: Defend Thesis

ELECTROPHYSIOLOGY OF ISCHEMIA

Ischemia is the lack of blood flow

- The lack of blood flow changes the conductance.
- Changes in conductance alter the activation wave.
- This often leads to heart failure

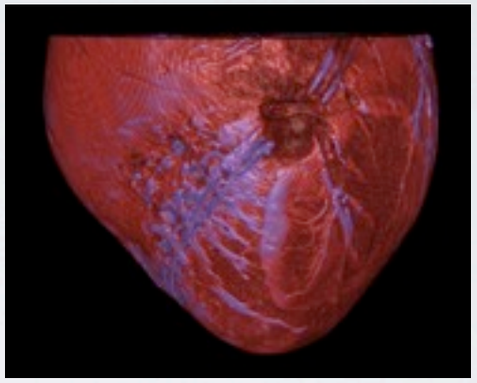
- These changes can be detected with an ECG

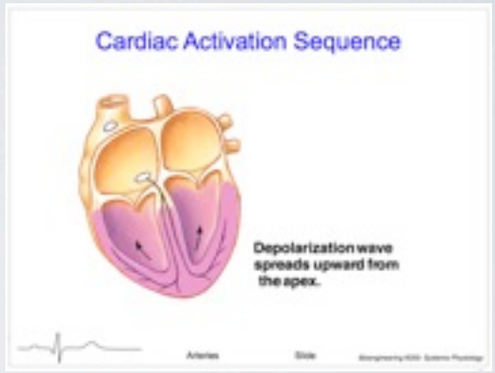
ECGs are insufficient to detect a large percentage of ischemia.

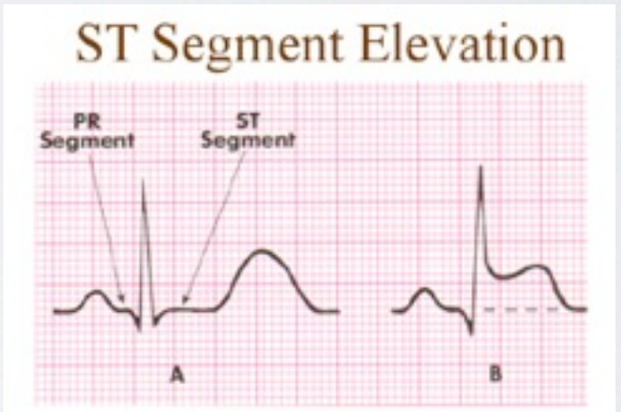
- Comparable ischemic regions produce dramatically different ECG signals.
- The cause could be Individual structure variability.

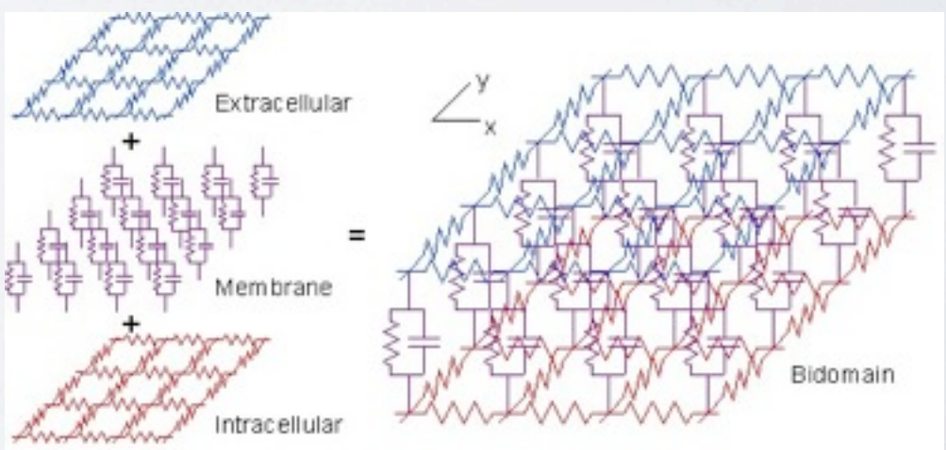
The bidomain is often used to model the spread of electrical currents in the heart.

- Two domains, extracellular and intracellular coupled by a membrae.
- $\nabla \cdot (M_i + M_e)\nabla \phi_e = -\nabla \cdot M_i \nabla \phi_m$



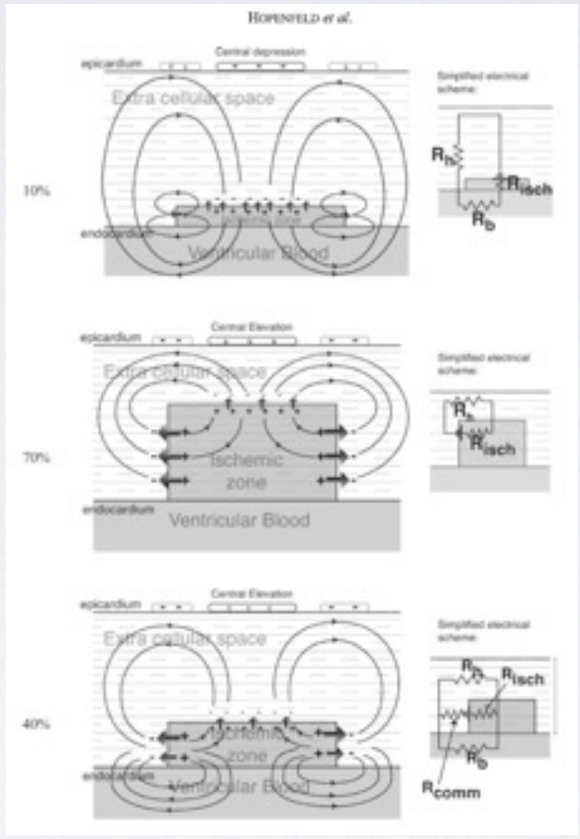


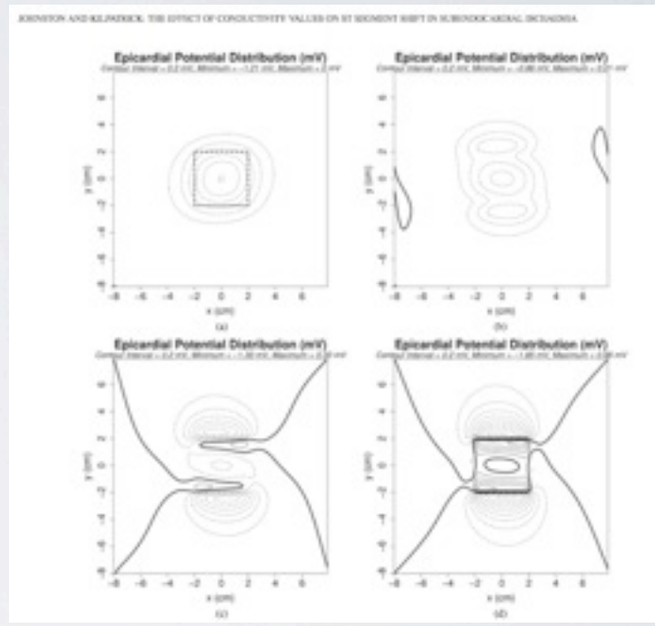




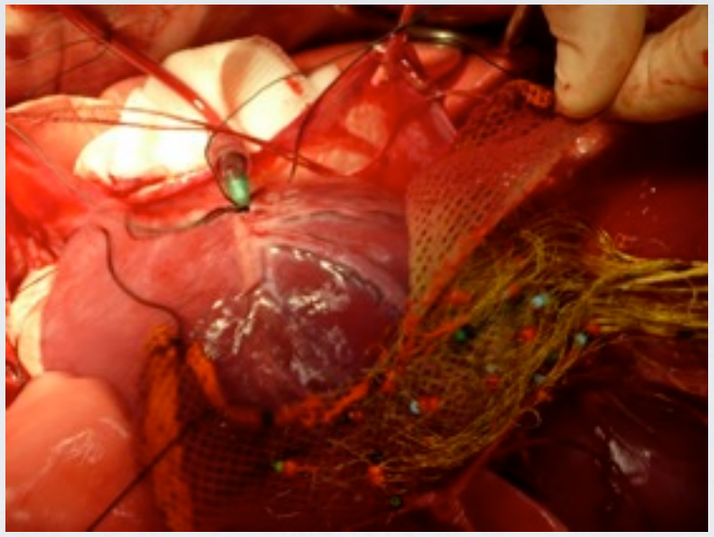
ISCHEMIA

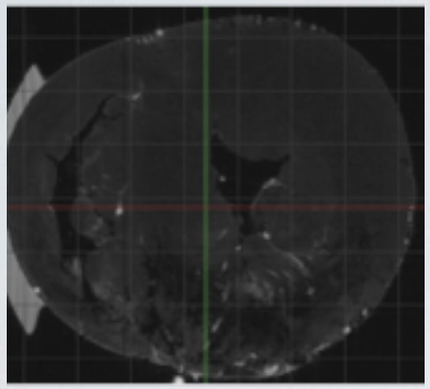
- Previous computational models do not simulate what is seen experimentally.
- There are may theories about the current loops during ischemia, but they also are not seen in measured data.
- Geometric factors may be the cause for many of the discrepancies.
- There is a need to validate cardiac bidomain models to actual data.

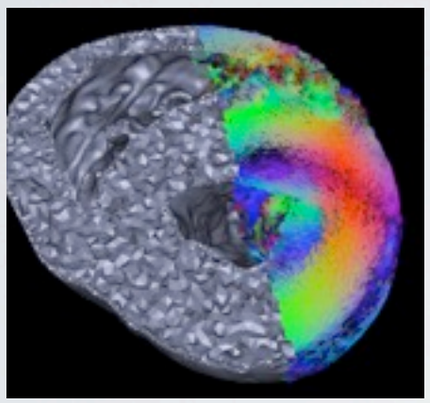


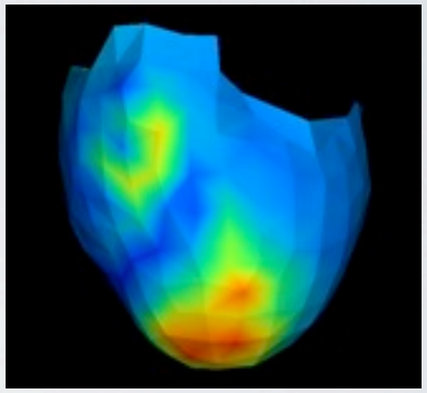


Subject Specific Modeling Pipeline







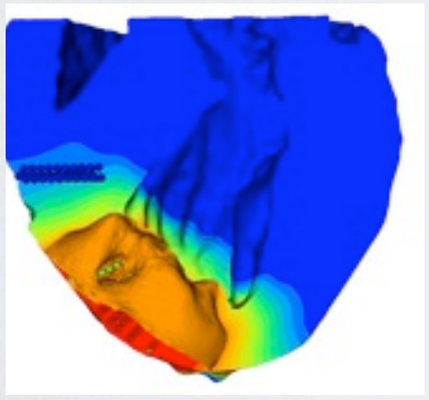


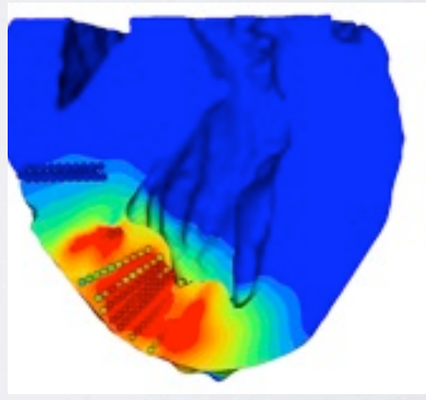
Model Creation

- Data Aquisition
- MRI/DTI
- Segmentation
- Meshing
  - Marching Cubes/Fairmesh/Tetgen
  - Particle System
- Map Fibers
- Define Ischemic Zone and Border Zone
- Map Conductivities
- Bidomain Solution

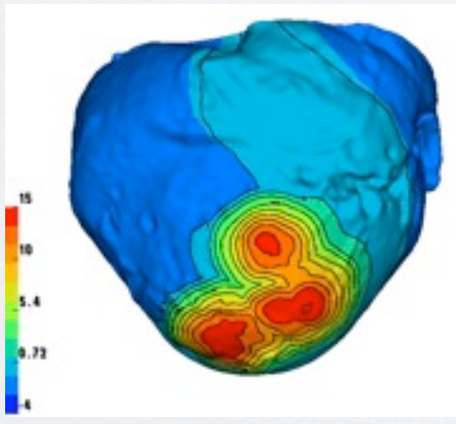
Reconstructing Data

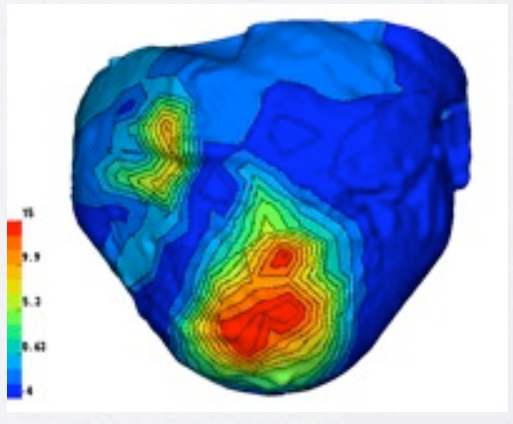
- Data Aquisition
- Sock/Needle Registration
  - Digitizing
  - Gd Markers
- Mapping/Interpolation
  - Thin Plate Spline Morph
  - Linear interpolation
  - Laplace Volumetric interpolation
- RMS comparison





Compare Simulated Data to Measured Data

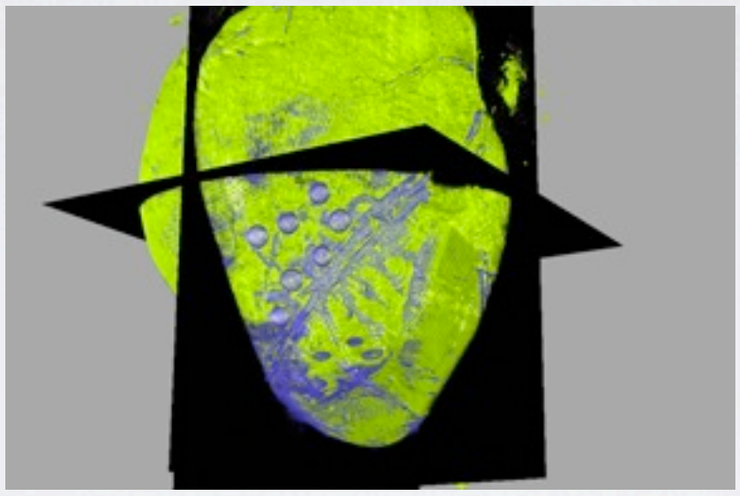




ISCHEMIA PIPELINE STATUS

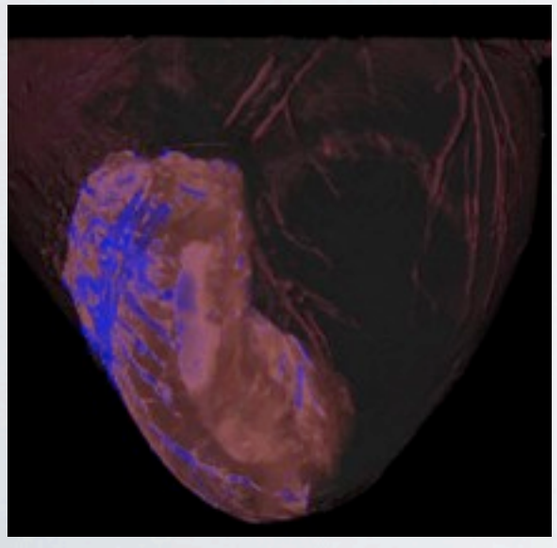
Model Creation Areas To Improve

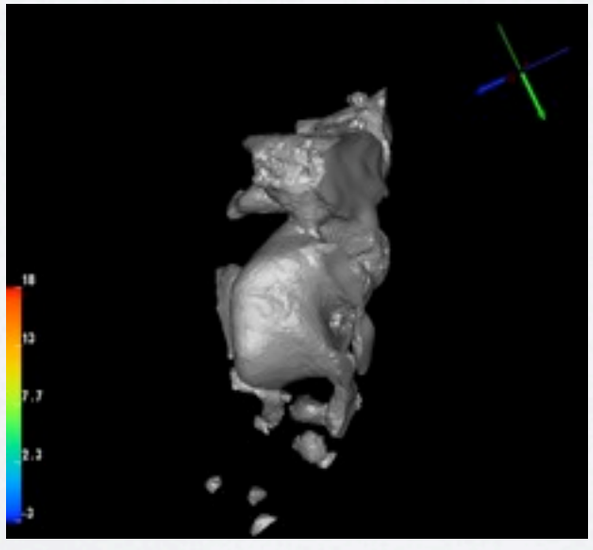
- How to define the perfusion bed and ischemic zone
  - Gd
  - Micro Spheres
  - CT
  - Needles
- Particle system under construction
- Border zone assumptions

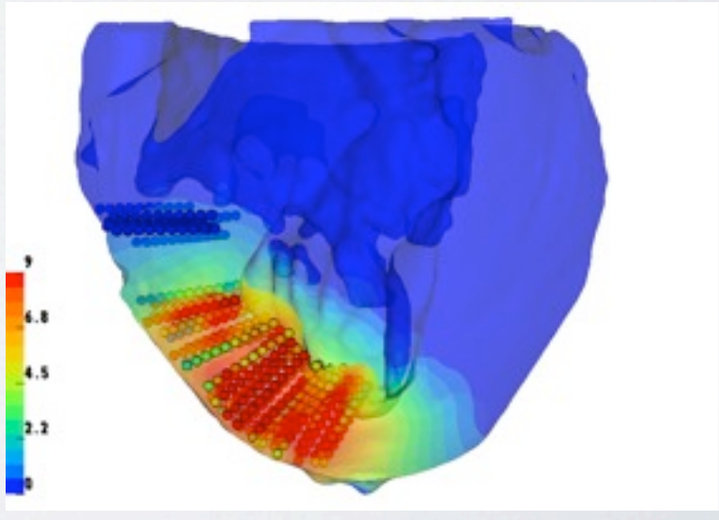


Reconstructing Data Areas To Improve

- Registration!
  - Digitize needles, sock, and markers
  - CT needles and sock
- Interpolation
  - Volumetric Laplace
  - Linear
  - WEB
- Comparing models
  - RMS
  - Gradients



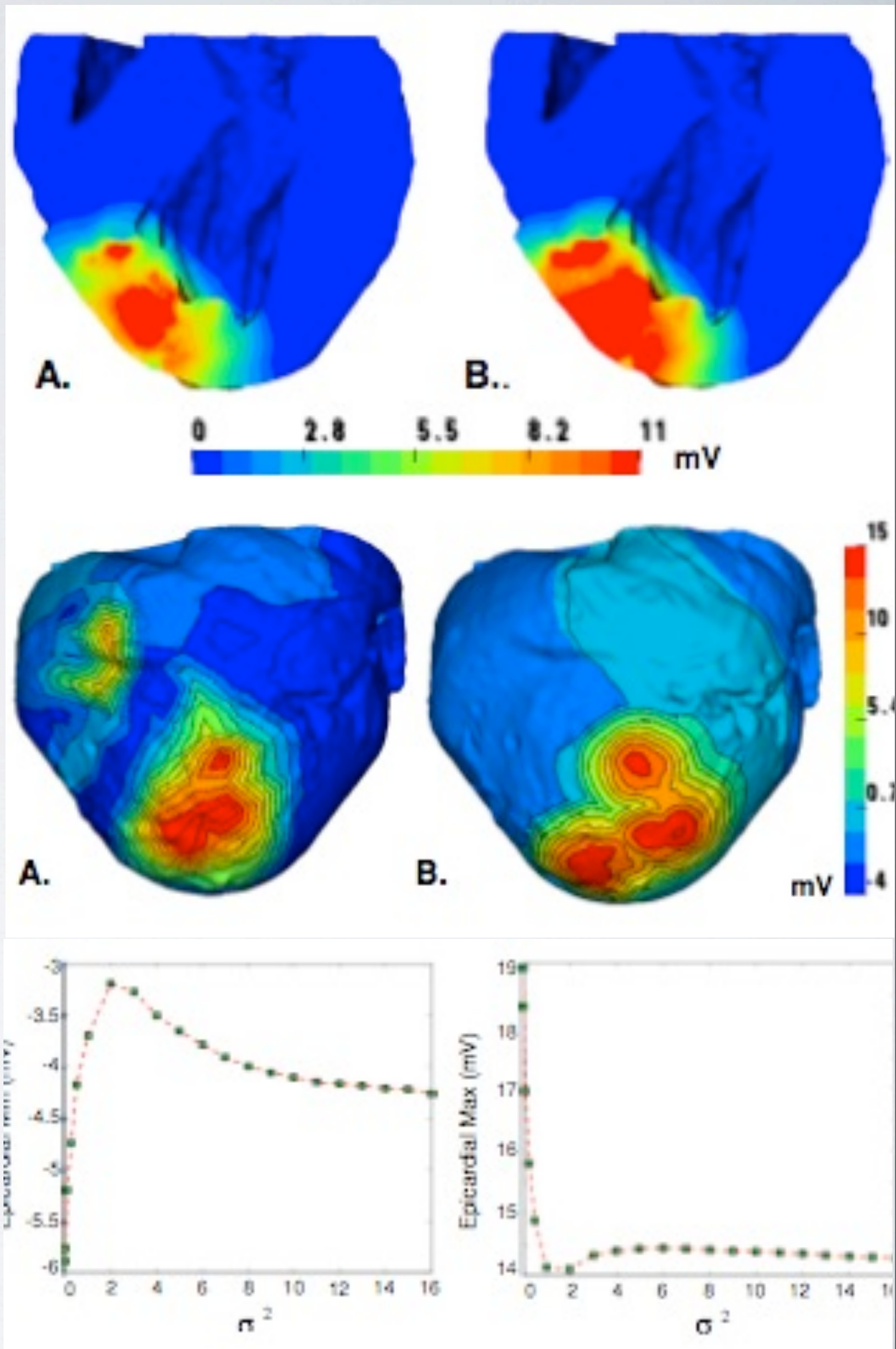




WC2009

Evaluating the Effects of Border Zone Approximations with Subject Specific Ischemia Models

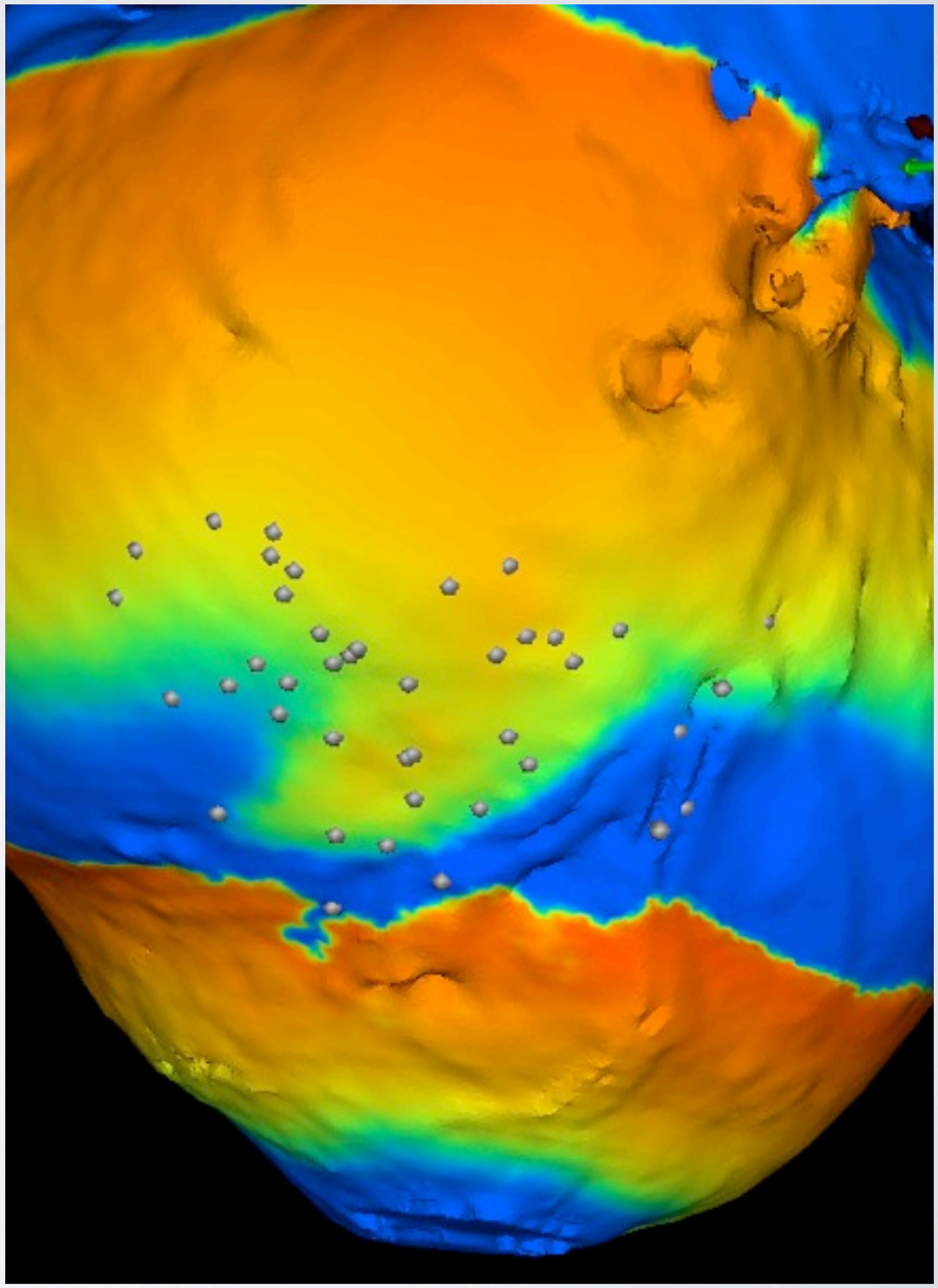
Abstract— **Current computational models of acute ischemia are deficient because of their inability to be validated against experimental data and their lack of geometric realism. Past models of ischemia have been based on geometric primitives or hearts for which no electrical measurements exist. One consequence is that it is necessary to make modeling assumptions that are not supported by measurements or direct validation with experiments. Based on our subject specific simulations and measurements, we hypothesize that assumptions about the nature and scale of the border zone play a significant role in determining the cardiac potential distributions from ischemic sources of injury current. Geometrically accurate models were created from Magnetic Resonance Imaging (MRI) and Diffuser Tensor Imaging (DTI) after an in situ canine ischemia experiment. The ischemic zone was defined based on transmural electrode readings and was used in a static bidomain simulation representing a time point during the ST segment. Varying the width of the border zone in the simulations changed the magnitude and distribution of epicardial depressions and elevations. We also found that a border zone with linear variation of potential from healthy to ischemic regions was not adequate to simulate measured potentials. A more sophisticated border zone that included an explicit region of partial ischemia was necessary to simulate the field gradients seen in experimental data.**



COMPUTERS & CARDIOLOGY

Wave Equation Based Interpolation on Volumetric Cardiac Electrical Potentials

Measurements of multiple time signals (mapping) in electrophysiology depends heavily on interpolation to reconstruct electrical potential fields across the surface of the heart or intramurally through the myocardium. In order to study normal and abnormal propagation due to infarcts, ischemia, or other forms of conduction delay, it is necessary for interpolation techniques to preserve the steep potential gradients that define the wavefront location, even in the face of inadequate spatial sampling by the electrodes. The quality of interpolation is of special importance in studying the features of the border zone between healthy and abnormal tissue, a critical region in the genesis of reentrant arrhythmias. Previous research from our group has demonstrated the effectiveness of wave equation based (WEB) interpolation especially in preserving sharp gradients on cardiac surface mapping, but this approach has not been extended to volumetric data. We propose that WEB interpolation will improve the accuracy of volumetric interpolation of cardiac potentials and remove artifacts in the areas with sharp gradients compared to other commonly used approaches. For this implementation and evaluation, we used simulated extracellular potentials (kindly provided by Dr. Natalia Trayanova, Johns Hopkins University) computed from a high resolution model of an infarcted canine heart. Virtual intramural needle electrodes were placed in a small region of the simulated heart and the potentials mapped to the nearest electrode. The time signals at each needle electrode site then provided the input (measured) data for the interpolation methods while the original time signals provided the gold standard test data. We implemented and compared trilinear, volumetric Laplacian, WEB trilinear, and WEB volumetric Laplacian (a novel hybrid of WEB and Laplacian methods) interpolation schemes through an entire activation wave based on root mean square (rms) value calculated at each time step. The WEB interpolation showed a 5 % advantage in rms value over the other methods when applied to the leading and trailing edges of the wave front. However, the WEB methods performed about 10% worse then the others at time points that did not include sharp gradients. The trilinear interpolation performed better than the volumetric Laplacian interpolation for both non-WEB and WEB approaches. The trilinear interpolation showed some significant artifacts that were reduced by approximately 40% by the WEB method. WEB interpolation was shown to be distinctly better for targeted situations such as sharp gradients and to reduce artifacts. However, it did not outperform other interpolation methods under all conditions,



RESEARCH IDEAS

Using fiber sheets to drive mesh anisotropy

Fiber helical angle and the impact on the bidomain solution

Geometric impacts of ischemic zones