The Effect of Variable Conductivity on Cardiac Excitation

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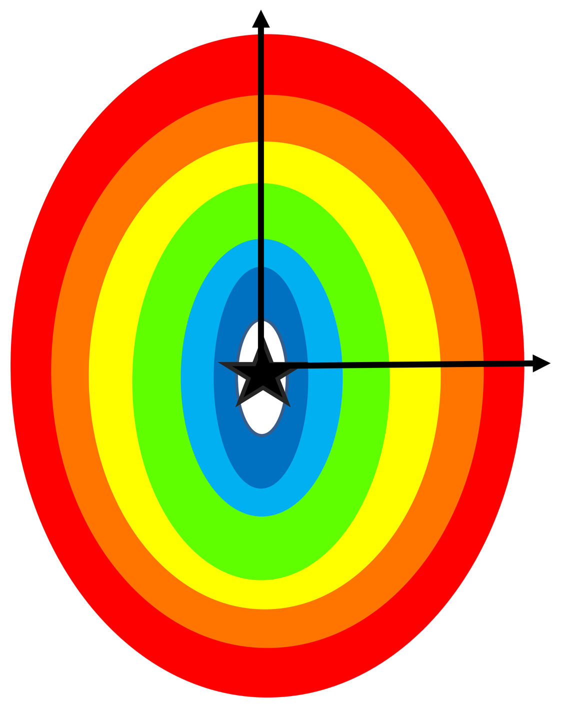
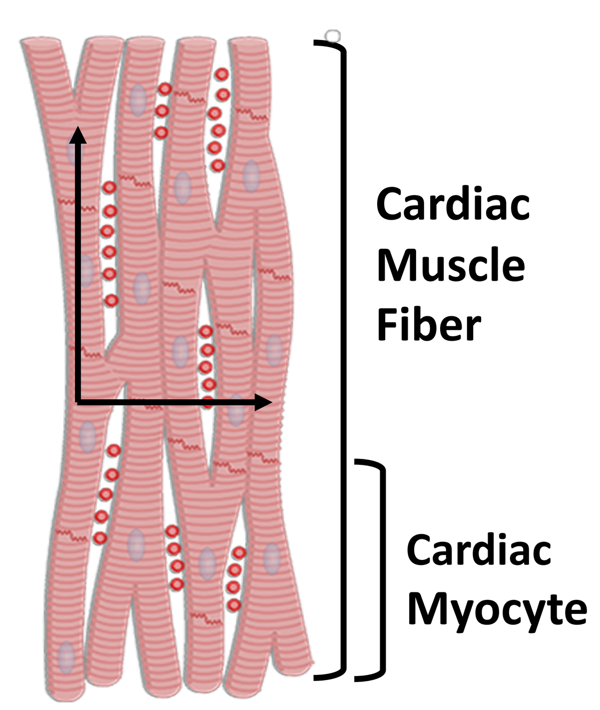
INTRODUCTION



The heart is driven by electrical activity that moves in waves through the tissue [1]. Cardiac arrythmias like bradycardia, tachycardia, and atrioventricular (AV) nodal block arise due to a malfunction in the hearts electrical system. Today these conditions are treated with cardiac pacemakers. Pacemakers are small implantable electronic devices, that regulate heart rhythm by delivering a small electrical stimulus to the cardiac tissue [2].

Figure 1. Model of Electrical Propagation. The white circle represents the initial point of simulation. The black star represents the electrical pacing of the heart. Propagation occurs in both the longitudinal (black) and transverse (grey) direction.



Cardiac muscle fibers are comprised of a network of cardiac myocytes. The resulting tissue structure facilitates the wave-like pattern of excitation in the heart.

Figure 2: Simplified Model of Cardiac Muscle Fibers. The blue ovals represent nuclei, the red lines symbolize gap junctions, and the white spaces indicate extracellular regions with the support matrix.

Conductivity, the permeability of tissue to electrical current, effects the rate at which electrical activity propagates throughout the heart. Conductivity can be influenced by many factors including tissue geometry, blood flow and ion concentration [3]. Conductivity in the cardiac tissue is anisotropic and can be parameterized into both longitudinal (parallel to fibers) and transverse (orthogonal to fibers) directions.

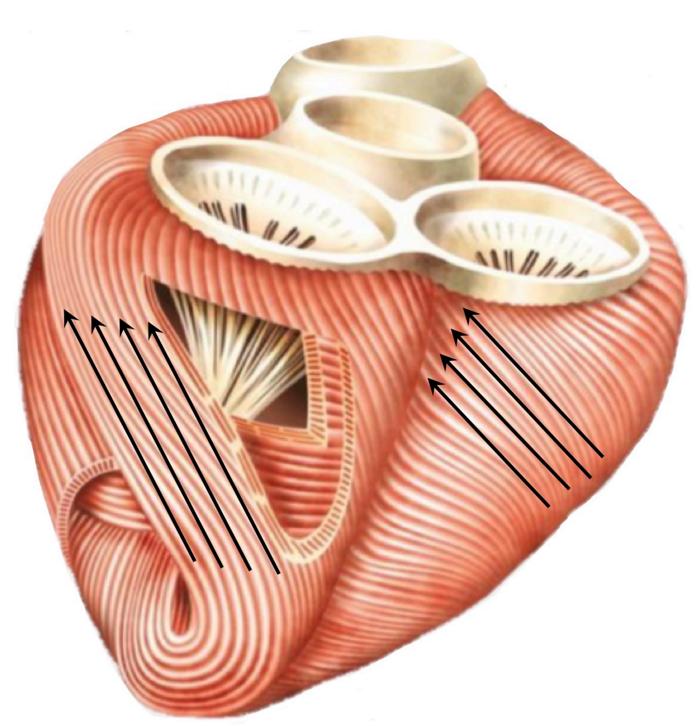


Figure 3. Conduction in the Cardiac Tissue. A model of the orientation of cardiac fibers in the ventricles is shown. The arrows represent the direction of the cardiac muscle fibers. Conductivity can be parameterized into longitudinal i.e., parallel to the arrow, and transverse (orthogonal to the arrow) direction.

METHODS

Computer modeling allows us to control the conductivity and simulate the spread of electrical activity. The goal of this study was to determine the effects of variable conductivity on the volume of initially activated tissue in the heart (the response to a pacemaker).

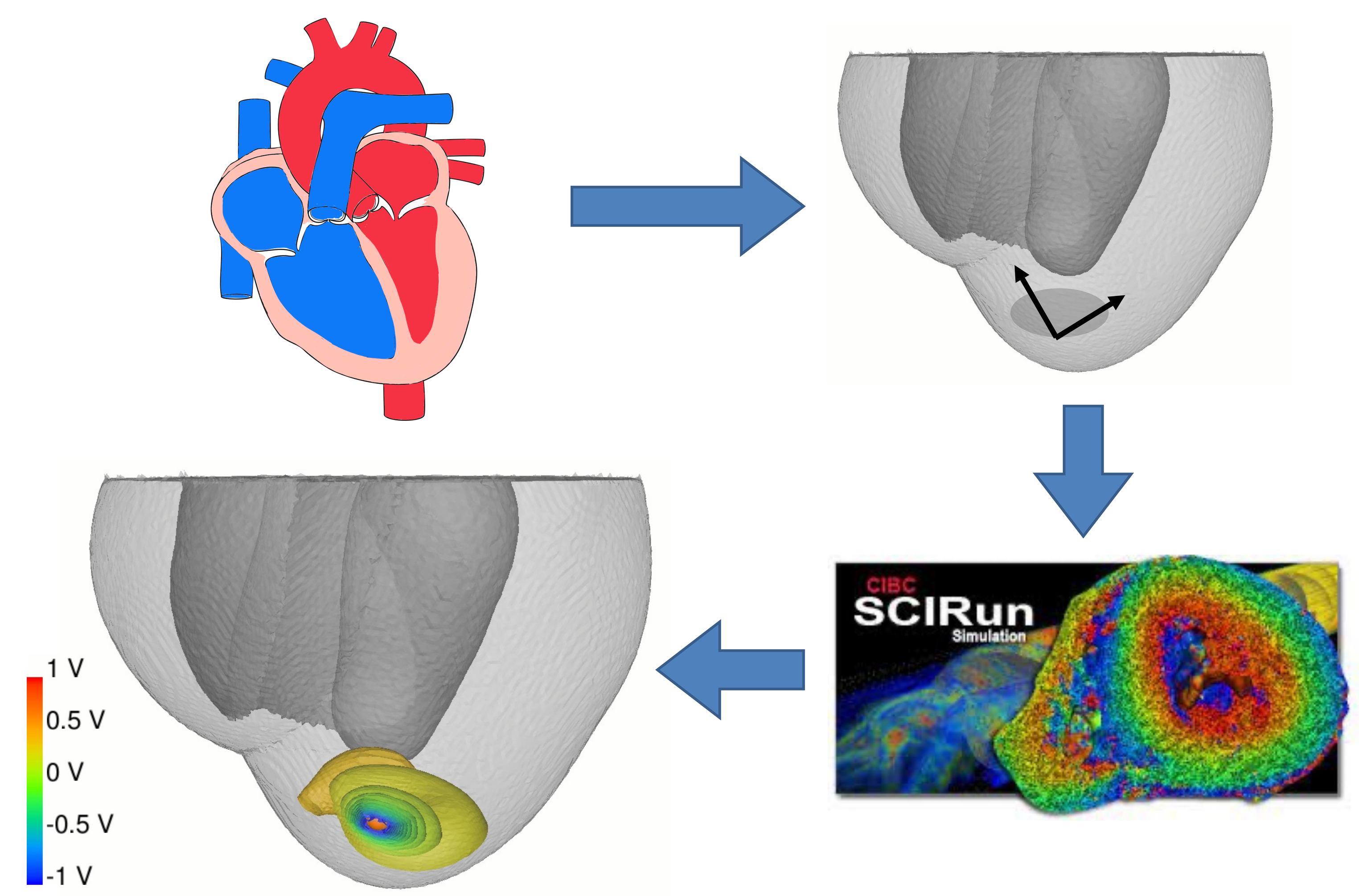


Figure 4. Simulation Implementation. Using MRI images, we constructed a computational model of the heart (top right) [4]. To implement the simulation, we used SCIRun, a computational work bench developed by the SCI Institute (bottom right/left). Colors in the bottom left correspond to isosurfaces extracted from the electric field.

RESULTS

Transverse (S/m) \ Longitudinal (S/m)	0.12	0.286	0.453	0.62
0.08	18.3	18.3	18.3	18.3
0.133	30	30	30	30
0.186	41.6	41.6	41.6	41.6
0.24	59.6	59.6	59.6	59.6

Figure 5. Volume of Activated Tissue Produced by Varying Longitudinal and Transverse Conductivities. The x-axis and y-axis correspond to transverse and longitudinal conductivities respectively [3]. The volume of activated tissue (mm^3) is represented by the colors/numbers displayed.

DISCUSSION

Our results suggest that transverse conductivity affects the volume of activated tissue, while longitudinal conductivity has no effect. These findings emphasize the influence of electrode location and tissue conductivity on stimulus success. If future studies validate these findings, this information could be used to help optimize the delivery of electrical stimuli in the setting of cardiac pacemakers.

FUTURE RESEARCH

The generation of patient-specific models allows clinicians to explore a wide range of heart diseases on a patient-by-patient basis. Used in the setting of cardiac pacemakers, this technology could improve both treatment outcomes and patient experience.

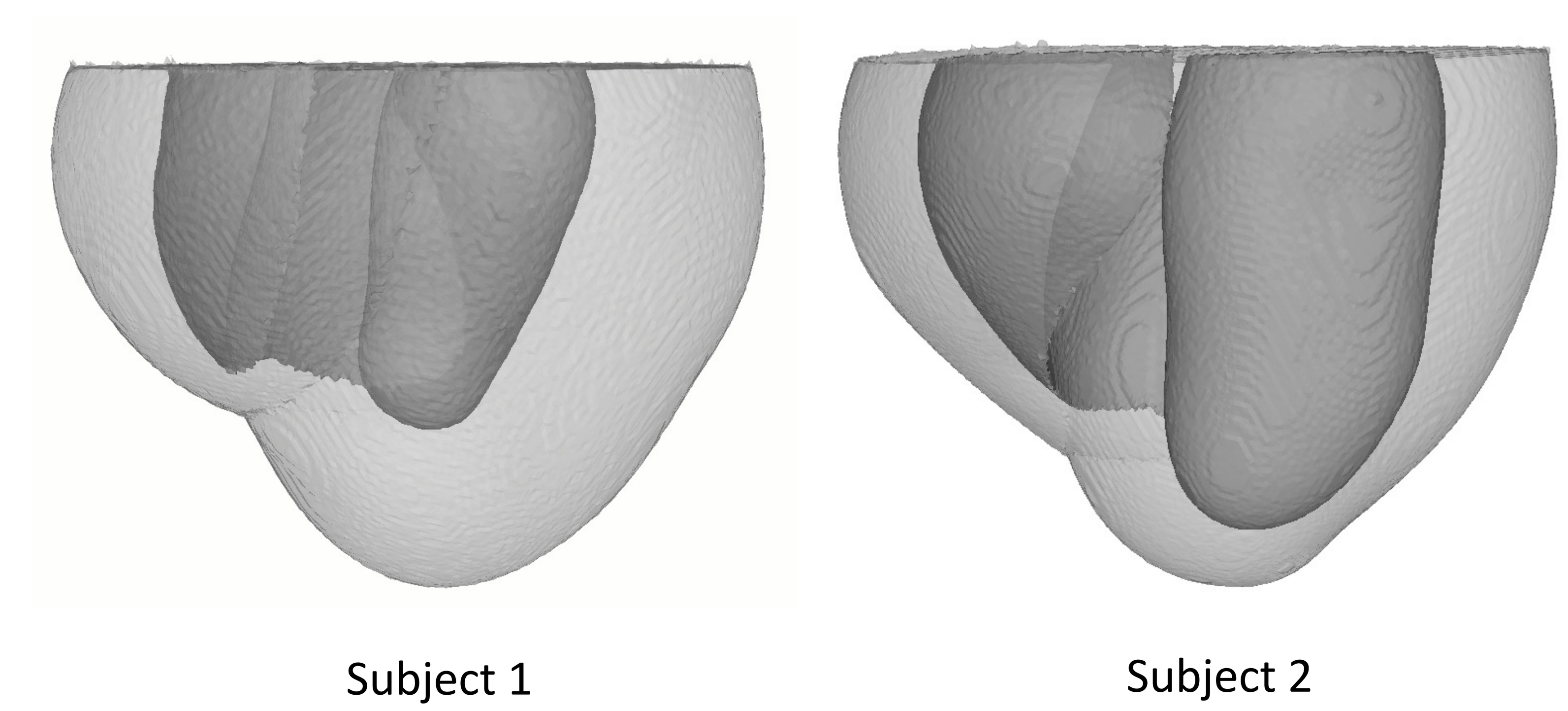


Figure 6. *Future Applications of Research. Subject 1 geometry (left) and Subject 2 geometry (right) allow us to simulate the effects of altered heart shape. We expect each to require different pacemaker settings.*

ACKNOWLEDGEMENTS

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