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Simulation of heart disorders using comsol multiphysics

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ABSTRACT

Micro electro mechanical systems (MEMS)also known as micro fabricated systems(MS) has evoked a greater interest in scientific and engineering communities. This is generally because of smaller size and better performance than other solutions, cost effective integration with electronics, large reduction in power consumption, etc…In this project SIMULATION OF HEART DISORDERS were detected using three equations such as FitzHugh-Nagumo equation, Landau-Ginzburg equation and Hermite-Quadratic element equation. We used the fourth order Hermite element for the complex landau-ginzburg equation because of less nonlinearit nonlinearites. We have used COMSOL MULTIPHYSICS for the simulations.

Introduction

The heart has a natural pacemaker that regulates the pace or rate of the heart. It sits in the upper portion of the right atrium (RA) and is a collection of specializes electrical cells known as the SINUS or SINO-ATRIAL (SA) node (Arumugam et al.,2009). Electrical signals created by the S-A node follow a natural electrical pathway through your heart walls. The movement of the electrical signals causes your heart's chambers to contract and relax. When a signal passes through a chamber wall, the chamber contracts. When the signal has moved out of the wall, the chamber relaxes. In a healthy heart, the chambers contract and relax in a coordinated way, or in rhythm.

When your heart beats in rhythm at a normal rate, it's called sinus rhythm. Any kind of abnormal rhythm or heart rate is called an arrhythmia. . When your heart beats out of rhythm, it may not deliver enough blood to your body. The heart produces rhythmic electrical pulses, initiated from a point known as the sinus node. The electrical pulses, in turn, trigger the mechanical contractions of the muscle. In a healthy heart these the chambers contract and relax in a coordinated way, or in rhythm.

The mitral valve is present in the left side of the heart, and functions normally to allow blood to flow into the left ventricle of the heart when it is filling (Espino et al., 2005, 2006a). This valve then closes when blood is pumped out from the heart towards the body. Failure of mitral valve of the heart can be fatal if it is not corrected surgically.

Methods:

Model overview:

This section presents two mathematical models describing different aspects of electrical signal propagation in cardiac tissue: the FitzHugh-Nagumo equations and the Complex Landau-Ginzburg equations, both of which are solved on the same geometry. Interesting patterns emerging from these types of models are, for example, spiral waves, which, in the context of cardiac electrical signals, can produce effects similar to those observed in cardiac arrhythmia.

Geometry:

A geometrically more accurate model has also been generated that matches a study in which measurements of pressure, flow and flow patterns were used to quantitatively validate the prediction of the model. The simplified elliptical model has been used to simulate the flow of electrical signal in the heart to find the disorders in the heart. The two dimensional model of the heart is first obtained from the simulation of mitral value of the heart.

The three- dimensional model is obtained from the electrical signal in the heart model.

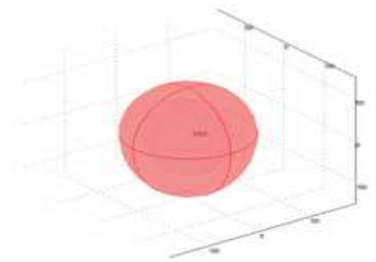

Figure 1: Model geometry

Fitzhugh-nagumo equation:

The FitzHugh-Nagumo equations for excitable media describe the simplest physiological model with two variables, an activator and an inhibitor (FitzHugh R et al., 1969).

In these heart models the activator variable corresponds to the electric potential, and the inhibitor is a variable that describes the voltage-dependent probability of the pores in the membrane being open and ready to transmit ionic current (Naugumo et al., 1962).

The equations are the following:

Here u1 is an action potential (the activator variable), and u2 is a gate variable (the inhibitor variable). The parameter α represents the threshold for excitation, ε represents the excitability, and β, γ, and δ are parameters that affect the rest state and dynamics of the system.

The boundary conditions for u1 are insulating, using the assumption that no current is flowing into or out of the heart. The initial condition defines an initial potential distribution u1 where one quadrant of the heart is at a constant, elevated potential V0, while the rest remains at zero.

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The adjacent quadrant has instead an elevated value v0 for the inhibitor u2. It is convenient to implement this initial distribution using the following logical expressions, where TRUE evaluates to 1 and FALSE to 0.

$$u_1(0,x,y,z) = V_0((x+d)>0)\cdot((z+d)>0)$$

$$u_2(0,x,y,z) = v_2((-x+d)>0)\cdot((z+d)>0)$$

Here d is equal to 10^{-5}, and it is included in the expressions to shift the elevated potential slightly off the main axes.

The complex Landau-Ginzburg equations:

The complex Landau-Ginzburg equations are:

The two variables u1 and u2 are the activator and inhibitor, respectively. The constants c1 and c2 are parameters reflecting the properties of the material. These constants also determine the existence and nature of the stable solutions.

$$\frac{\partial u_1}{\partial t} - \Delta(u_1 - c_1 u_2) = u_1 - (u_1 - c_3 u_2)(u_1^2 + u_2^2)$$

$$\frac{\partial u_2}{\partial t} - \Delta(c_1 u_1 + u_2) = u_2 - (c_3 u_1 + u_2)(u_1^2 + u_2^2)$$

As in the previous model, the boundary conditions are kept insulating. The initial condition, which gives a smooth transition step near z = 0, are the following:

$$u_1(0,x,y,z) = \tanh(z)$$

$$u_2(0,x,y,z) = -\tanh(z)$$

Modeling in comsol multiphysics:

The simplified geometry is quite straightforward to create using the drawing tools in COMSOL Multiphysics. The FitzHugh-Nagumo and Landau-Ginzburg equations are also readily entered in one of the PDE-based application modes.

It is important to note that these equations are strongly nonlinear. It is therefore necessary (especially in full 3D models like these) to use a much finer mesh or use higher element order than in these examples to get results with some degree of reliability for the time intervals of interest. This is particularly important in solving the complex Landau-Ginzburg equations, which describe inherently chaotic phenomena. They are highly sensitive to perturbations in the initial value and similarly to numerical errors during the course of the time-dependent solution. We recommend the use of the fourth-order Hermite element for the complex Landau-Ginzburg equation.For the reasons above, the results presented here are only intended as a first rough estimate of the qualitative behavior that you can expect the system to show under a given stimulus. Consequently, higher-order elements, finer meshing, and smaller relative and absolute time dependent tolerances clearly give quantitatively more correct simulation results. These improvements may require several hours of computational time to solve the equations, while the rough model described here should solve within around 20 minutes on a standard PC. When attempting these types of large models we strongly recommend the use of 64-bit platforms.

The landau-ginzburg equation:

The equation parameters and initial condition used here lead the diffusing species (u1) to display characteristic spiral patterns with growing complexity over time.

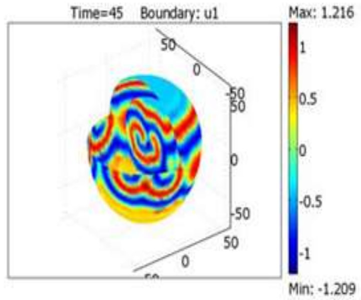

Figure 3: Solution to the Complex Landau-Ginzburg equations at times t = 45 s .

The Fitzhugh-Nagumo equations:

The plots in Figure 2 below show the action potential u1. To visualize the solution on the inside, a quarter of the outside shell of the heart and one of the chamber surfaces are suppressed in the plot. The parameters used in the model along with the initial pulse lead to a rentrant.

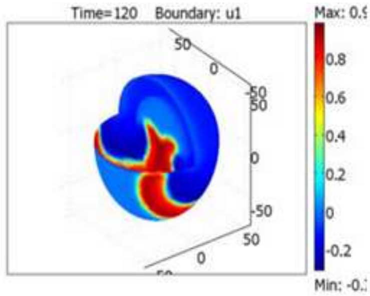

Figure 4: Solution to the FitzHugh-Nagumo equations at times t = 120 s.

Results:

Fourth order hermite element equation:

It is important to note that these rdertherefore necessary to use a much finer mesh or use higher element order than in these two equations to get results with some degree of reliability for the time intervals of interest. So we go for the fourth-order Hermite element for the complex Landau-Ginzburg equation.

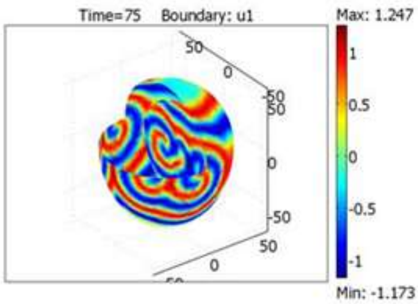

Figure 2: Solution to the fourth order hermite element equations at times t=75 s.

Conclusion:

The simulation of heart disorders using comsol multiphysics was done accordingly thereby here we done using fourth order hermite element, it would also be straightforward to replace the rather simple FitzHugh Nagumo equations and landau-ginzburg equation with a physiologically more realistic mathematical model.

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