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ELECTROMECHANICAL MODEL OF HUMAN ATRIAL TISSUE USING THE DISCRETE ELEMENT METHOD

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1 Introduction

The function of the heart is to generate a sequence of mechanical muscle contractions, which are triggered by electrical excitation waves. Such mechanical contraction provides a driving force for cardiac tissue to pump blood, maintaining circulation. Any disturbance to the electrical activity can impair cardiac mechanical dynamics via the electrical–mechanical coupling and vice versa. It still remains a challenge to underpin the dynamical interactions between cardiac electrical and mechanical activities. The aim of this project is to construct a bio-physically detailed computer model of the human atria to investigate the interaction between the electrical and mechanical coupling of the human atria, from cellular to tissue scales.

The equations governing the electrical and mechanics of cardiac cells are often stiff and numerically unstable. The atria is especially complex, with many detailed regions presenting different geometrical structures and electrophysiological behaviour: this makes traditional continuum mechanics difficult to apply. In this work, we use the discrete element method (DEM) to analyse the electromechanical behaviour of 2D tissue.

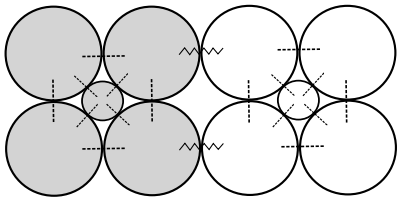

Figure 1: Cell and particle arrangement in the model. A different contact model is used within a cell (dashed lines) and between cells (zig–zag lines).

2 Method

DEM tracks the position and velocity of a large number of "particles". It can be applied to the visco-elastic medium of cardiac tissue by bonding the particles together using a suitable contact model. Each cell consists of five particles that are bonded together: each cell is also coupled to nearest neighbouring cells (see Figure 1). In the present study, the cells are arranged in a uniform pattern for simplicity.

The electrical behaviour of each cell is governed by the model of [1]. Electrical propagation from cell to cell is simulated by solving a reaction–diffusion equation. The electrical model also calculates various ionic concentrations, such as Ca^{2+}, K^+ and Na^+. The mechanical behaviour is governed by the model of [2]. The particle position and calcium concentration from the electrical model are taken as input, and the model outputs the active tension for each cell. This is applied as a force to each particle, causing cell contraction. The discrete element equations are then solved, updating particle positions across the tissue.

3 Results & future work

A model consisting of 31x31 coupled cells (4805 particles) is run, producing 1 second of simulation. The center cells are stimulated, producing an electrical wavefront to propagate throughout the tissue. Figure 2 shows the voltage of each cell as time progresses. The active tension of each cell is plotted in Figure 3. The tension causes the tissue to contract to 80% of its original size, shown by the grid size of each figure. The parameters of the model are chosen so that this contraction and the wave speed emulate atrial tissue.

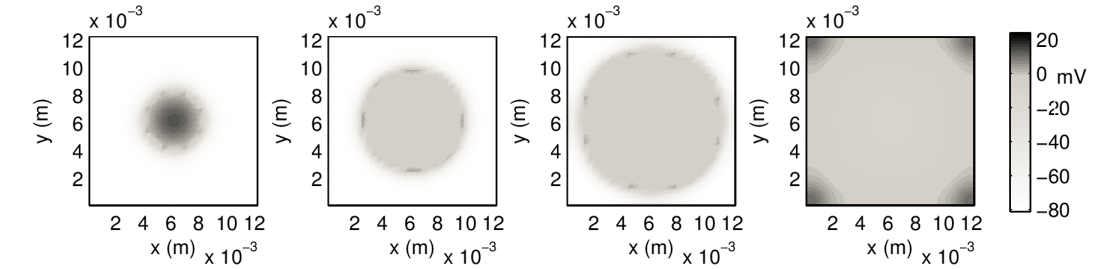

Figure 2: The voltage in each cell in across the tissue at $t = 10, 15, 20, 30$ ms.

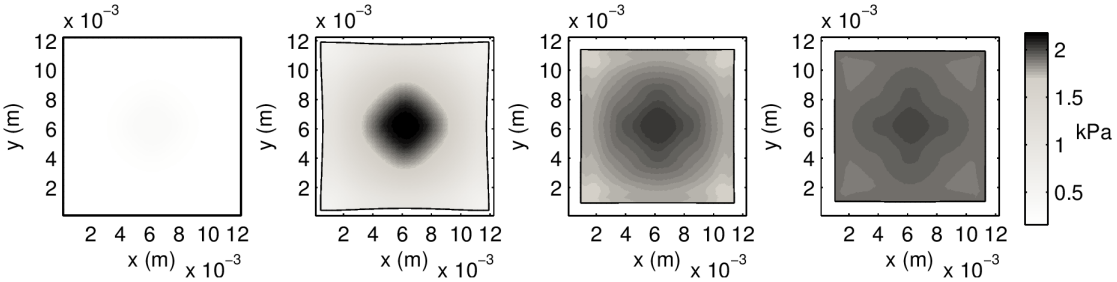

Figure 3: The active tension in each cell across the tissue at $t = 25, 50, 75, 100$ ms.

In the future, the model will be extended to 3D. Cell and particle configuration will be constructed to mimic the geometry of the atria using recent medical imaging – DEM allows easy detailed construction of different atrial regions. The computation will be parallelised to increase efficiency. The complete model will be verified against recent experimental findings. The model can then be used to simulate various kinds of atrial arrhythmia, and make inferences about alleviating their effect.

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