A Sphere Model for Atrial Fibrillation

Tigany Zarrouk & Mattia Gaggi **Supervisor**: Kim Christensen
Condensed Matter Theory Group—Imperial College London

1 Introduction

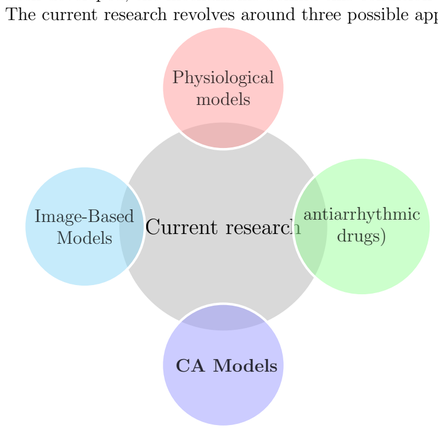
Atrial Fibrillation (AF) is a type of cardiac arrhythmia and one of the major causes of stroke and heart failure. AF is also the most widespread cardiac condition, with over 30 millions of people worldwide suffering from it. In the UK, expenses related to this disease account for more than 1% of the total budget of the National Health Service, which is more than 800 million pounds.Atrial fibrillation usually manifests itself in patients affected through alterations of the normal cardiac rhythm lasting short periods of time (also called fibrillation episodes).

Each heart beat originates as an electric signal in the sinoatrial (SA) node that propagates first into the atria, then through the atrioventricular (AV) node, through Purkinje fibres and finally from the ventricular endocardium to the ventricular epicardium. The electric signal is conducted in the cardiac muscle cells thanks to the polarisation mechanism of the cell membrane.
When the electric impulse propagates a single muscle cell goes through three stages:

- *Excitable state*: the muscle cell is at rest with a negative built up potential.
- *Excited state*: the muscle cell is excited by its excited neighbours and the Voltage of the cell is at its peak.
- *Refractory state* :the muscle cell goes through a phase during which it can't be excited again - this period is called *refractory period).*

Where the refractory period depends on the last time a cell was excited and is always fixed to a constant.

AF is correlated to the amount of **fibrosis** in the cardiac tissue which generates a process called reentry.
During reentry the electric signal wavefront propagation breaks. It has been shown a clear link between fibrosis and AF Even though many treatments have been developed, the mechanisms behind this condition are not completely understood and AF remains a major topic in medical research.
The current research revolves around three possible approaches:



Our research is based on expanding on the wrok done by Kim Christensen on CA (Cellular Automata) models [3].

2 Kim Christensen's Model

2.1 Description of the model

In the publication "a Simple Model for Identifying Critical Regions in Atrial Fibrillation" [3], Prof. Christensen produced a simple 2D model for AF. The cardiac cells were arranged in a squared grid with horizontal connections, with a percentage of **transversal connections** (to reproduce the effect of fibrosis) and a percentage of **dysfunctional cells**. Dysfunctional cells are excited by neighbours with a fixed probability.

Propagation Rules the model

- *Excitable state*: at time step t=0, each cell at rest is an element in the grid
- *Excited state*: at t=1, the cell is excited by one of its *4 neighbour cells*, and it can excite one the excitable neighbour cells at the next time-step.
- *Refractory state* :from t=2 onwards, the cell goes through the refractory state for t=T time-steps before becoming excitable again/

2.2 Results

The result show that AF naturally arises from the model itself. **It is important to note that this model is the only model ever created where arrhythmia naturally occurs from the structure of the heart** instead of being put in by hand in some way (as for instance adding by hand a new source of electric impulses.
In addition the simulations produced by the model show a correlation between fibrillation and fibrosis . There is a threshold value of vertical connections beyond which AF is produced spontaneously (without changing refractory period or conduction speed). This matches real data according to which AF is correlated with fibrosis. The model also shows that burning the area affected by AF effectively stops the arrhythmia, which has been recently discovered to be the case.

3 Implementing Restitution

Even though in Prof.Christensen model, the refractory period of each muscle cell was always fixed, this is not what happens in a real heart. In a real heart the refractory period depends on the heart beat rate and on the last time each cell it was excited. The relationship between refractory period and heart beat rate is called restitution.
In the first part of our project, we implemented restitution in Kim Christensen model in order

4 Kim Christensen's model on a Sphere

In research by Fedotov, a cellular automaton model was constructed on the surface of a triangulated sphere to model spiral rotor waves on a closed, heterogeneous surface [4]. It was shown that both a decrease in refractory period and conduction velocity from a "healthy" myocardium state, where no irregular excitation waves above 300bpm are observed, resulted in an area where spiral waves were formed. In addition, a multi-electrode system was created to study the localization of AF sources by simulated electrograms.

5 Bibliography

References

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