Visualising a computational model of ventricular fibrillation in mammalian myocardium

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Introduction

Ventricular fibrillation (VF) is a deadly cardiac arrhythmia. The electrical mechanism(s) underlying VF are not well understood, although there is evidence that re-entry plays an important role.

The aims of the work presented here were to

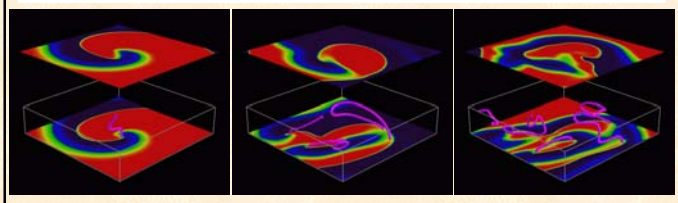
• Implement a computational model of VF in mammalian ventricles.

• Develop and validate a method to quantify the dynamics and interaction of re-entrant filaments in the model.

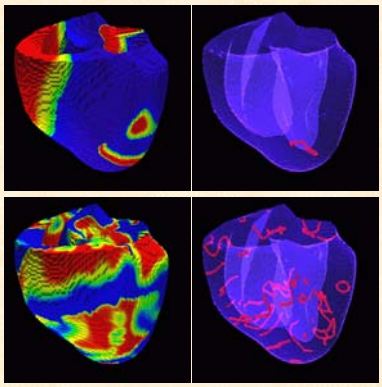
The wider aim of this project is to validate computational models of VF by relating model behaviour to experimentally observable quantities.

Breakdown of re-entry into fibrillation

Our initial conditions were a single re-entrant wave with a transmural filament. The filament became twisted and extended until it touched a boundary and fragmented, resulting in complex patterns of action potential propagation.



Surface views of depolarised tissue (red) and repolarised tissue (blue), and volume views of filaments (pink) 30 ms (left), 130 ms (middle) and 230 ms (right) following initiation of re-entry in 82 x 82 x 16 mm anisotropic slab. During 2 s of simulated VF the mean (SD) APD and cycle length were 50 (18) ms and 96 (24) ms respectively.



Simulated re-entry and fibrillation in the Auckland canine geometry. Top panel shows surface activity (left) and filament (right) 350 ms after initiation re-entry in the LV free wall. The bent filament results in both re-entrant and focal activation patterns on the epicardial surface.

Bottom panel shows activity 1 s after initiation of re-entry. There are now 40 filaments giving rise to very complex patterns of activity on the epicardial surface.

Computational model of VF

We simulated action potential propagation using the 3D cable equation, with excitability described by the Fenton Karma (FK) model and restitution set to reproduce that of the Beeler Reuter model [Chaos 1998;8:20-47]. The model was solved using explicit forward differences with a time step of 0.1 ms, a space step of 0.33 mm, and no-flux boundary conditions. We simulated re-entry in slabs of tissue 10, 16, and 20 mm thick, and with 120º rotational anisotropy between top and bottom surfaces.

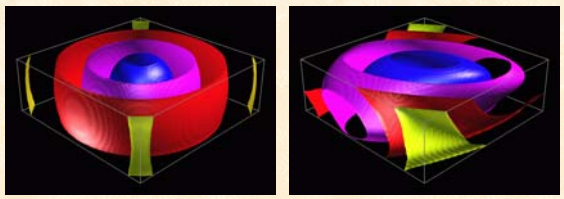
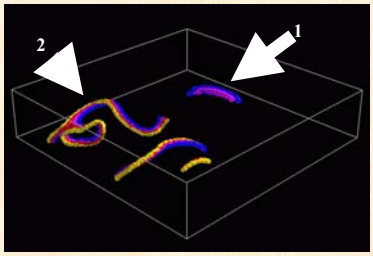


Figure shows isosurfaces of active tissue in simulated 60 x 60 x 20 mm slabs resulting from a point stimulus at the centre. In an isotropic slab with D=0.1 mm^2ms^{-1} (left) surfaces show active tissue 20 (blue), 40 (pink), 60 (red) and 80 ms (yellow) after stimulation. Plane wave conduction velocity is 0.44 m s^{-1}. In an anisotropic slab with D along fibres = 0.2 mm^2ms^{-1} and D across fibres = 0.05 mm^2ms^{-1} (right) surfaces show active tissue 40 (blue), 60 (pink), 80 (red) and 100 (yellow) after stimulation. Plane wave conduction velocities were 0.56 m s^{-1} along fibres and 0.18 m s^{-1}across fibres.

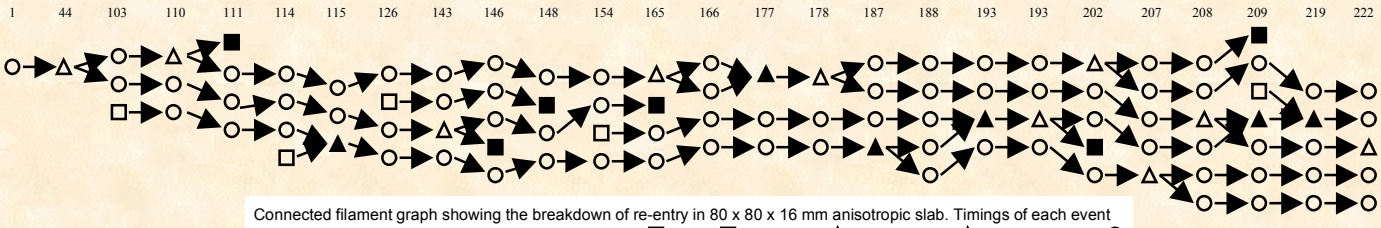
Identification and tracking of filaments

During re-entry an action potential continuously propagates into electrically recovered tissue, and rotates around an unexcited but excitable region of tissue. In 3D this region is a thin filament where dV_m/dt =0 and V_m has a constant value. Identifying an tracking the behaviour and interactions of filaments offers a way to quantify the complex electrical activity of VF.



Filaments detected 162 (blue), 164 (pink), 166 (red) and 168 ms (yellow/ after initiation of re-entry in 82 x 82 x 16 mm anisotropic slab. One ring filament dies after 164 ms (1) and another filament bifurcates to form a new ring (2).

We located filaments from the intersection of dV_m/dt=0 and V_m=-20mV isosurfaces, and tracked filaments from overlap in successive time frames. We could then construct a connected graph showing the birth, death, bifurcation and amalgamation of filaments as shown below.



Connected filament graph showing the breakdown of re-entry in 80 x 80 x 16 mm anisotropic slab. Timings of each event in ms are shown in the top panel. Symbols denote birth □, death ■, bifurcation △, amalgamation ▲, and continuation ○ of a filament, and arrows denote connected events.

Conclusions

We have implemented a computational model of VF in mammalian ventricular tissue, and have developed a method for analysing the dynamics and interaction of filaments. Computational models of VF yield complex spatiotemporal patterns of re-entrant waves that can be difficult to relate to data from experimental VF. Analysis of filament dynamics and the wave patterns visible on the model surface provide a way both to validate computational models of VF against experimental data, and to interpret experimental data in terms of filament behaviour.

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