Re-entrant waves in contracting excitable ventricular tissue to study mechano-electrical feedback and arrhythmias

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Introduction

- Many cardiac arrhythmias are driven by re-entrant electrical sources [1].
- Spiral wave break up is linked with ventricular fibrillation [2].
- Mechano-electrical feedback (MEF) can be proarrhythmic or arrhythmic [3].

Objectives

- To investigate mechanisms of ectopic pacemaking due to mechano-electrical feedback (MEF) via stretch-activated channels (SACs).
- To examine the effects of tissue contraction on the dynamics and stability of re-entrant electrical sources.

Methods: Electrical activity

Modified Aliev-Panfilov model [4]:

activation:

\[
\frac{Dv}{Dt} = \frac{1}{\sqrt{\varepsilon_C E_C}} \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - k v (v - a)^2 - I + I_N
\]

recovery:

\[
\frac{D\delta}{Dt} = \frac{1}{\varepsilon_\delta} \left[ \frac{\partial^2 \delta}{\partial x^2} + \frac{\partial^2 \delta}{\partial y^2} \right] - \gamma (1 - \delta)
\]

SACs:

\[
I_C = G_C (v - E_C)
\]

Model parameters:

- \( a = 0.05 \)
- \( k = 8 \)
- \( E_C = 1.0 \)
- \( G_C = 0.5 \)

Finite difference method parameters:

- \( \Delta t = 0.03 \)
- \( \Delta x = \Delta y = 0.6 \)
- 49x49 grid pts

Methods: Tissue mechanics

Governing equations [5]:

- finite deformation elasticity
- non-homogeneous strain
- stress equilibrium
- 8x8 finite elements

Passive material response:

\[
W = \frac{1}{2} \varepsilon^T [\lambda_1 \delta_1 I - \delta_1 I_0] \varepsilon
\]

Active contraction:

- isotropic, homogeneous
- local mechanical coupling
- active tension \( (T_a) \);
- increasing \( T_a \); decreases period.

Electromechanical coupling:

- active tension \( (T_a) \) drives mechanical contraction
- conductivities \( (D_{xy}) \) and SACs modulated by deformation \( (C_{xy}) \)

No deformation \( \Rightarrow \) no pacemaking

Contraction + MEF \( \Rightarrow \) pacemaking

Wave propagation due to a single external stimulus, in the absence or presence of mechanical contraction.

With no deformation, just one depolarising wave resulted from the stimulus. Time-space plot (3) for the thick vertical line marked in panel (1).

Methods: Integral space-time plots

Drift trajectories

Integral of the excitation variable along:
- the horizontal spatial X-axis; and
- the vertical Y-axis; versus time.

(c) Depending on the site of initiation, the pacemaker drifted to one of five attractors (red spots) symmetrically located throughout the medium [6].

Result: Contraction and MEF \( \Rightarrow \) resonant spiral drift

- Tip trajectories were tracked for a stable spiral wave under non-contracting and contracting electromechanical conditions.
- In the absence of contraction, the spiral wave core followed a stationary circular meander pattern.
- Contraction and MEF caused the spiral tip to follow a non-stationary meander pattern.
- The re-entrant wave was attracted and further meandered around the centre of the medium.

References


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