The Effects of Heart Structure on Action Potentials

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Introduction

Electrical activation and propagation in the heart both depend on the excitability of cardiomyocytes, their 3D arrangements and the progress of action potentials between adjacent cells. Abnormality in any of these factors can give rise to rhythm disturbance and reentrant activation, such as the case following a heart attack in which the cell arrangements are altered by scars [1].

Structure-based computational models that include the details of myocyte arrangements and structures such as blood vessels have been previously developed [2]. In this study, structure-based models were used to simulate electrical activation across a section of the left ventricular (LV) wall of a rat. We aimed to explore how action potential (AP) morphology, current kinetics and activation spread are affected when a cut is artificially induced in a cardiac tissue wedge.

Methods

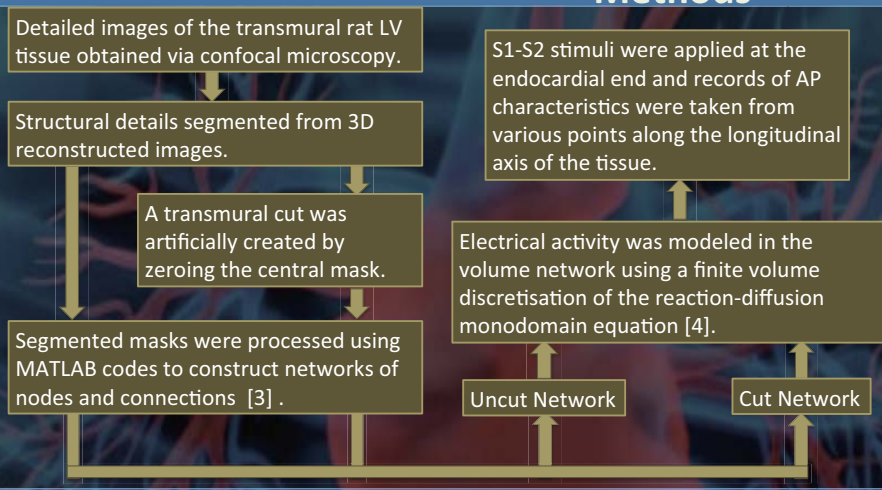

Figure 1. A segmented mask of the rat left ventricular (LV) tissue wedge. White represents cardiac tissue and the thin black lines in the centre represent cleavage spaces.

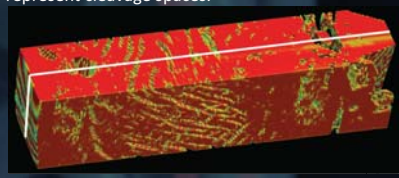

Figure 2. The full network of the rat LV tissue with the artificially simulated transmural cut marked by a white solid line. The epicardial end is on the left and the endocardial end is on the right.

Results

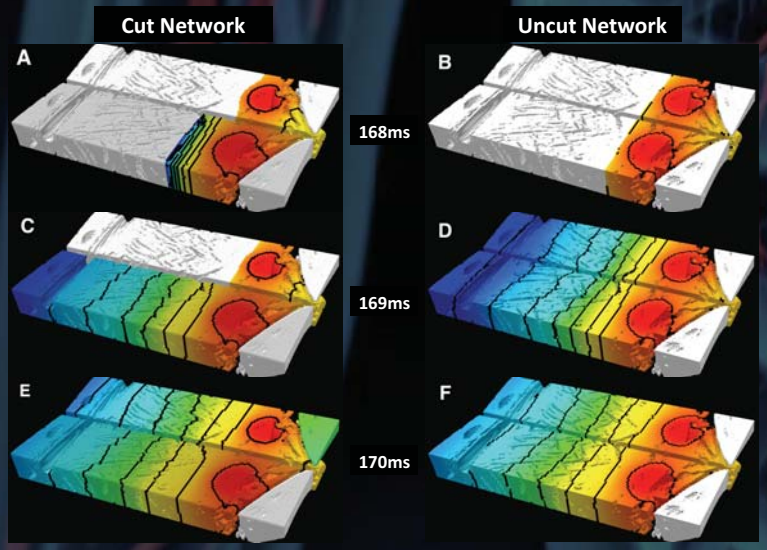

Figure 3. Split view of the network showing relative activation times of AP elicited from S2 stimuli at various coupling intervals. The activation front is slightly smoother in the uncut network.

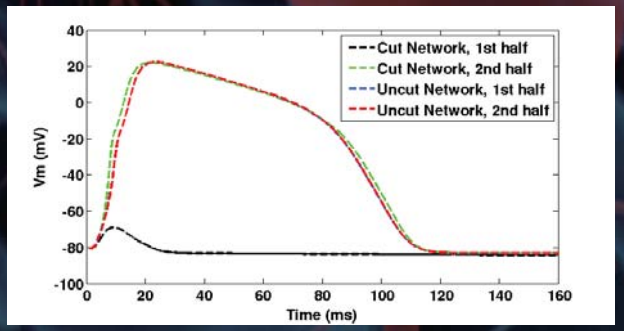

Figure 4. AP traces obtained at the centre of each half of the network when the coupling interval of 169ms is used. The AP traces support the observations in figure 3, that only (the 2nd) half of the tissue network developed a full AP. The AP duration in the 2nd half of cut network is marginally longer than that in the uncut network.

Conclusions

- In this project, we have successfully simulated an artificial cut in a structure-based network model of the rat left ventricular tissue that prevents ionic flow across this boundary.
- This study reveals that the effective refractory period and AP morphology are not heavily affected by the introduction of a cut surface.
- The activation front is smoother in the uncut network because there are more path options around the cleavage spaces.
- Computer modelling has provided insight to the detailed characteristics of electrical propagation in cardiac tissue.

References

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[2] Trew, M., Smaill, B., & Pullan, A. (2005). What of Cleavage Planes? The State-of-the-Art in Microstructure Modeling of Cardiac Activation. International Journal of Bioelectromagnetism, 7(1), 299-302.
[3] Trew, M., Le Grice, I., Smaill, B., & Pullan, A. (2004). A finite volume method for modeling discontinuous electrical activation in cardiac tissue. Annals of biomedical engineering, 33(5), 590-602.
[4] Rutherford, S. L., Trew, M. L., Sands, G. B., LeGrice, I. J., & Smaill, B. H. (2012). High-Resolution 3-Dimensional Reconstruction of the Infarct Border Zone Impact of Structural Remodeling on Electrical Activation. Circulation research, 111(3), 301- 311.