Inference of Atrial Conduction Properties from Activation Time Measurements Using Computational Modelling and Finite Element Methods

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Atrial conduction properties play a key role in the initiation and maintenance of cardiac arrhythmias, yet their quantitative characterization in human tissue remains challenging. In particular, quantitative estimates of the effective diffusion governing electrical propagation are highly relevant for characterizing atrial conduction. This work addresses the inverse problem of inferring diffusion properties from experimentally measured activation times in human atria.

Our experimental data consists of activation times recorded at different locations across the atria (Figure 1). Using these activation times defined at the nodes of a finite element mesh, we aim to reconstruct effective diffusion coefficients, with emphasis on anisotropic conduction along and across fiber directions. To account for the electrophysiological basis of propagation, cellular models, namely Fenton–Karma [1] and Grandi [2] formulations, are incorporated to link ion dynamics with tissue-level conduction. In the anisotropic case, fiber orientation is introduced using a rule-based method defined on a triangular mesh, allowing the distinction between longitudinal and transverse propagation.

The propagation of the membrane potential across cardiac tissue is described by (eq.1):

$$C_m \frac{dV}{dt} = \nabla \cdot (\mathbf{D}\nabla V) - I_{ion} \tag{1}$$

In (eq.1), $(\nabla \cdot (D\nabla V))$ is the diffusion term, with $\mathbf{D}$ acting as the diffusion tensor that describes how fast and in which direction the electrical wave travels through the anisotropic tissue. The velocity of propagation of a wavefront across the cardiac tissue is described by (eq.2) in terms of its curvature, K [3].

$$c = c_o - C_1 \cdot K \tag{2}$$

In (eq.2), c_0 is the velocity of a planar wavefront. To facilitate the development and validation of the methodology, we first consider simplified one-dimensional and two-dimensional isotropic and anisotropic problems solved using finite difference methods. Based on (eq.2), we calibrate c_0 and C_1 parameters as functions of the effective diffusion coefficient in the propagation direction. By estimating wavefront velocity and curvature from activation-time data, we can infer the effective value of the diffusion coefficient in the propagation direction locally. Using the spectral decomposition of the diffusion tensor, the diffusion along and across fiber direction can be deduced, if fiber direction is known.

The methodology is subsequently implemented within a finite element framework and tested on both an icosphere and a realistic atrial mesh. For activation data generated from a single simulation, the proposed approach successfully recovers the anisotropic diffusion coefficients when fiber orientations are known. Furthermore, by combining activation maps obtained from multiple simulations with different stimulation sites, the method is also able to infer the underlying fiber orientation.

Current work focuses on extending the framework to experimentally derived atrial geometries segmented into anatomical regions. In this setting, diffusion coefficients are assumed to be constant within each region, and the inverse problem is reformulated to estimate regional diffusion properties.

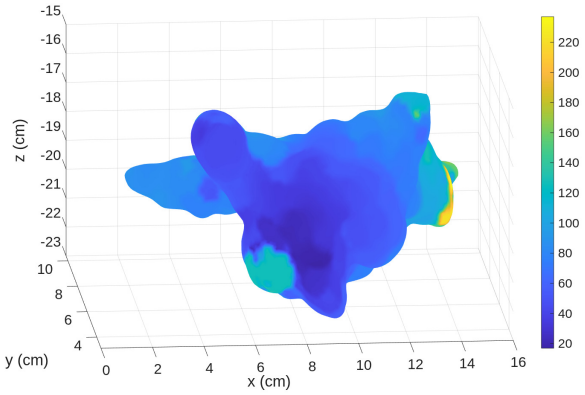

Fig. 1. Experimental measures of activation times on atrial surface.

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[2] E. Grandi et al., *Human Atrial Action Potential and Ca^{2+} Model*, Circulation Research, vol. 109, no. 9, pp. 1055–1066, 2011.

[3] H. Dierckx, *Dynamics of Wave Fronts and Filaments in Anisotropic Cardiac Tissue*, Ph.D. thesis, Ghent University, 2010.