Source Estimation in Cardiac Fibrotic Substrate from Intracardiac Signals

Pascual Tejero Cervera[1], Jorge Sánchez[2], Olaf Dössel[3], and Axel Loewe[2]

[1]Karlsruhe Institute of Technology, Institute of Biomedical Engineering, Karlsruhe, Germany
[2]Universistat Politècnica de València, Departamento de Ingeniería Electrónica, València, Spain

Background

Atrial fibrillation (AF) is a supraventricular tachyarrhythmia characterized by an uncoordinated rhythm of the atria. Often, fibrosis, which is the appearance of interstitial myofibroblasts and collagen, is associated with recurrent arrhythmia for AF. Ablation therapies can be an effective alternative to stop it, but it is necessary to explore a methodology that precisely localizes regions that sustain and promote AF.

Objective

Explore an inverse reconstruction by obtaining the signals from the electrograms of simulated reentrant activity in and around fibrotic patches. We obtain a map of the transmembrane voltages (TMV) of the cardiac tissue to localize strategic points in the cardiac tissue that promote AF.

Methods

Tissue patches of 50x50x1 mm with a spatial resolution of 0.2 mm were simulated in openCARP. Electrograms were computed with three different grids of electrodes (8x8, 12x12 or 16x16) with an interelectrode distance of 3 mm at two distinct distances to the tissue, 0.5 or 1 mm.

Simulations have been carried out so far in a control case (plane wave), reentry case and fibrotic tissue (plane wave with two different tissues of 10% and 60% collagen respectively, and both with 2% of myofibroblasts and the rest were myocytes).

Reconstruction of the transmembrane voltage at the tissue surface was performed in MATLAB software using a second order Tikhonov regularization, which deals with the ill-posedness of the inverse problem. Additionally, the Boundary Element Method was used to calculate the extracellular potentials of the sources at the surface of the tissue resembling unipolar electrograms.

The root mean square error (RMSE) of activation times (AT) was calculated to validate the methodology between the reconstructed signals (obtained in MATLAB) and the signals from the electrodes (ground truth from openCARP). ATs were calculated using the position at a time of the minimum value of the first derivative. Afterward, the minimum and maximum values of the AT were computed, and the RMSE was calculated between the ground truth and reconstruction with the same parameters (equal distance and electrode grid).

Results

Table 1 shows the RMSE of the maximum and minimum of AT between simulations with the same parameters. The RMSEs are lower for the control and reentry case (the latter with one exception) compared to the fibrotic case.

	Distance (mm)	Min and max RMSE (ms)		
		Electrode grid		
		8x8	12x12	16x16
Control case	0.5	(3,2)	(2,4)	(2,3)
	1	(5,2)	(3,4)	(4,8)
Reentry case	0.5	(3,2)	(12,4)	(12,8)
	1	(3,2)	(1,6)	(26,268)
Fibrotic case	0.5 (10% collagen)	(16,13)	(9,16)	(5,24)
	0.5 (60% collagen)	(74,25)	(0,38)	(0,38)

Table 1: RMSE of the minimum and maximum AT for the control case, reentry case and fibrotic case for each of the electrode distributions.

Discussion

In the control case, the propagation of the tissue is homogeneous; it is expected that the reconstruction will be similar to the ground truth and most errors obtained are not high. On the other hand, the good results in the reentry case determine that the methodology is also useful for the 8x8 and 12x12 electrodes. However, increasing the tissue electrode distance leads to an increase of the error, as it can be seen for the electrode grid of 16x16.

Finally, for the case of fibrotic tissue, higher error values were obtained. Although these errors could indeed be reduced by optimizing parameters (e.g., lambda value for the Tikhonov regularization), the values obtained are acceptable when the errors are lower than 20 ms.

To conclude, some reconstructions could improve and reduce the RMSE to precisely localize the reentry voltage points to stop AF effectively.