Non-invasive Characterization of Atrial Arrhythmic Driving Mechanisms in Computer Models

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Introduction: atrial tachycardia (AT), atrial flutter (AFL) and atrial fibrillation (AF) are among the most common cardiac arrhythmias and are related to several risk factors. They are driven by localized sources (ectopic focus in AT, macro-reentrant circuit in AFL and rotors in AF) and their non-invasive localization is important for ablation therapy planing. In this study, we aim to characterize the non-invasive behavior of these driving mechanisms.

Method: a realistic three-dimensional computer model of the atria was used to generate atrial and body surface potential mapping (BSPM) signals (4 AT, 4 AFL and 11 AF). 567 BSPM leads were reshaped to a 2D representation, interpolated to a 30x65 grid and band-pass filtered (fc=2 and 20Hz). Dominant frequency (DF) maps were obtained using a combination of peak detection in Welch periodograms and activation detection via wavelet transform modulus maxima. The driver mechanism's frequencies (f_{drive}) were estimated by selecting the highest DF in the maps. Phase was obtained applying Hilbert transform on signals filtered around the driver frequency ($\pm$1Hz) and the spatio-temporal distribution of phase singularity points (SPs) was analyzed using histograms (heatmaps) and connecting SPs along time (filaments).

Results: f_{drive} were estimated non-invasively with absolute error of 0.06 ± 0.03, 0.18 ± 0.06 and 0.45 ± 0.20Hz for AT, AFL and AF respectively. These frequencies were reflected in a smaller portion of the torso for AF than AT or AFL ($p < 0.05$). Filament durations were shorter in AF ($p < 0.05$), followed by AT and AFL. Mean rotation frequency from the filaments was similar to the estimated driver frequency. SP clusters in heatmaps were smaller in AFL than AF but had higher SP density ($p < 0.01$); AT presented intermediate values ($p > 0.05$).

Conclusion: the proposed customized methodology was applied for the analysis of AT, AFL and AF, highlighting intrinsic non-invasive characteristics of the mechanisms both in frequency and phase domains.

Frequency results

	# of f_{drive} regions	f_{drive} region size (% of torso)	DF range (Hz)
AT	1.50 ± 0.50	77.94 ± 20.96	1.28 ± 0.39
AFL	1.00 ± 0.00	97.62 ± 2.10	0.25 ± 0.25
AF	2.36 ± 0.41	22.91 ± 10.51	2.43 ± 0.23

Phase results

	# of SP clusters	Cluster size (% of torso)	SP density	SPs/s
AT	3.25 ± 1.44	0.57 ± 0.10	4.73 ± 1.29	1.26 ± 0.51
AFL	1.75 ± 0.25	0.35 ± 0.17	14.85 ± 4.36	1.27 ± 0.42
AF	3.73 ± 0.57	1.29 ± 0.22	1.89 ± 0.47	1.84 ± 0.47