Automatic Generation of Patient-Specific Digital Twins from Body Surface Potential Maps: from Ectopic Beats to Sinus Rhythm

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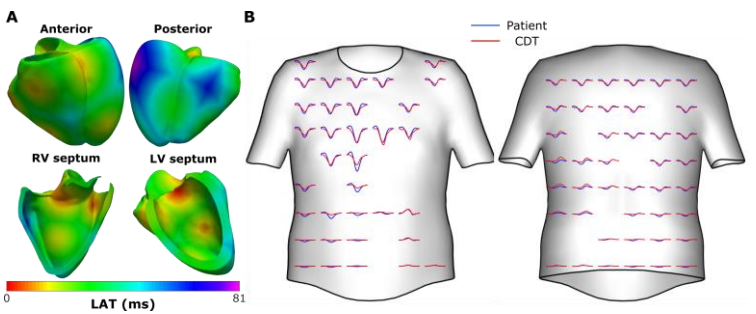
Introduction. Cardiac digital twins (CDTs) typically require cross-sectional imaging or invasive recordings. We propose a non-invasive genetic algorithm (GA) guided by a spectral cost function to generate CDTs directly from body surface potential maps (BSPM) with non-invasive data.

Methods. The framework is a GA that combines an isochron-based forward model with a developed spectral cost function based on Laplace-Beltrami modes to identify activation sources. Validation included a standalone cost function assessment on 10 synthetic and 2 clinical ectopic cases; and an end-to-end GA evaluation on multi-source synthetic configurations and one clinical sinus rhythm patient (7 focal sources).

Results. Ectopic origins were correctly identified in all clinical cases. In-silico costs increased monotonically with distance from the focus. For the in-silico GA evaluation, GA maintained high accuracy across multi-source configurations. For the clinical sinus rhythm patient, reconstruction yielded a mean BSPM correlation of 0.85 ± 0.37, as illustrated in the attached figure.

Conclusions. This imageless framework accurately reconstructs complex activation patterns from BSPM, offering a non-invasive pathway for patient-specific CDT personalization in clinical settings.



Clinical sinus rhythm CDT. (A) GA-estimated LAT map. (B) BSPM signals over torso: patient recording (blue) vs. CDT (red). Only valid leads are shown.