Evaluation of Automata-based Simulations for Atrial Fibrillation in 2D/3D Geometries Reproducing Disease Progression

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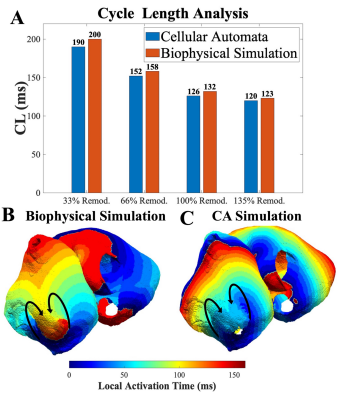
Background: This study aims to investigate the viability of a Cellular Automaton (CA) model for the simulation of atrial electrophysiology under healthy and pathological conditions, in a timely and cost-effective manner, in comparison to conventional biophysical simulations.

Methods: To calibrate the restitution properties defining the CA, we simulated with Koivumäki's atrial model a rectangular pacing atrial tissue (N_1=2106 cells). This calibrated CA was used to reproduce fibrillatory conditions on a square atrial tissue (N_2=109512 cells) and on a complete 3D atrial geometry (N_3=284578 cells) to assess the similarity reproducing healthy and chronic AF patterns against biophysical simulations. The comparison between the models was made by analyzing values such as Action Potential Duration (APD), Cycle Length (CL), and Local Activation Times (LAT).

Results: Predicting APD values (APD^{+1}) considering both previous APD (APD^{0}) and diastolic interval (DI) resulted in a smaller error (1.41±2.12 ms) than estimating APD with DI alone (2.12±1.33 ms, p=0.0052). This CA calibration allowed to simulate functional reentries in a 2D domain under {33, 66, 100, 135}% of electrical remodeling, which showed a CL mean difference of 6.25±2.87ms (< 5%, Fig A). Further simulations on a realistic 3D geometry demonstrated an average difference of 9.6±7.6ms in the LAT of sinus rhythm. Lastly, comparable re-entrant patterns were observed when inducing fibrillatory patterns in chronic AF conditions (Fig B-C). All CA results were 21 faster than biophysical simulations (17 sec of computation time per second of simulated time).



Conclusion: CA models can reproduce biophysical simulations in different substrate conditions when trained with pacing data. CA have the potential to provide an efficient tool to simulate AF under different degrees of disease progression, and be performed in acceptable clinical timeframes.