Project title: Digital Twins for Stratification and Therapy Selection for Atrial Arrhythmia Patients

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Aim of the project

Atrial tachycardia (AT) and fibrillation (AF)are the most common arrhythmias and a major cause of morbidity. Their diagnosis and management imposes a substantial burden on healthcare systems, warranting efficient clinical approaches for stratifying AT/AF patients and selecting therapy. Digital Twins (DTs) can help(i) integrate data from multiple sources, including patient imaging, image-based modelling, clinical signals and health records, and (ii) provide an efficient tool to support clinical decision-making using available patient data.

This project aims to:
-Create Digital Twins of the atria and upper body using patient MR imaging and ECG data;
-Simulate DTs to establish links between AT/AF in the atria and ECG pattern on the body;
-Train AI models to predict AT/AF origins in the DT atria from underlying MRI & ECG data;
-Apply AI models to identify arrhythmia status and suitable therapy targets for a patient.

Project description

Atrial arrhythmias, including tachycardia (AT) and fibrillation (AF), affect over 2% of the global population and impose a substantial burden on healthcare systems. The need to manage large cohorts of AT and AF patients warrants efficient clinical approaches for stratifying the patients and selecting suitable therapy. Atrial arrhythmias are characterized by rapid and irregular atrial excitations reflected in abnormal P-wave morphologies in ECG. These include various re-entrant or focal excitations originating from atrial regions outside the natural pacemaker. For successful treatment of AT/AF (e.g., by catheter ablation, CA), it is crucial to locate such excitations. However, due to complexities of atrial structure and function, such key locations are difficult to establish without using invasive modalities.

The ECG is the most common noninvasive method for monitoring activity of the heart by measuring the body surface potential (BSP) distribution. Links between BSP and underlying electrical activity on the heart surface can be established by solving the inverse problem. However, it's implementation requires large multiple lead arrays to map BSP in detail not provided by the standard 12-lead ECG used in the clinic. Alternatively, computational models can be used to solve the forward problem and establish links between the origin of atrial activity and BSP. In our proof-of-concept work, models of the human atria and torso were applied to explore such links [1] and locate AT excitations from 12-lead ECG[2].

Cardiac Digital Twins (DTs) are digital replicas of patient hearts derived from clinical data that match like-for-like all available clinical observations. Due to their inherent predictive potential, DTs show high promise as a cost-effective modality aiding in clinical decision- making. This project will develop Atrial Digital Twins to integrate multi-modal patient data and create efficient tools to support stratification and therapy selection for AT/AF patients. Specifically, the data will include patient MRI to reconstruct structure of the atria and upper body, image-based 3D biophysical models of atrial excitation and resulting BSP, 12-lead ECG recordings from the patients, and records of the patient's arrhythmia status. The model simulations will be applied to dissect links between the type of arrhythmia, the origin of arrhythmic excitations in the 3D atria and the ECG pattern on the patient's body.

Analysis of large volumes of patient data and 3D simulations require substantial time and computational resources, hindering application of this approach in the clinic. Deep learning (DL) can help overcome such limitations: (i) DL models can be trained to extract known parameters and find new metrics in from abandunt multi-modal data; (ii) once trained, DL models can make predictions even from limited patient data, and on a clinical timescale. We have previously developed DL models trained on a combination of imaging and image-based modelling of AF patients undergoing CA[3].The 3D atrial models enabled linking structural features of the patient images with functional outcomes of the simulations. The trained DL models were then able to predict CA outcomes from patient images only.

This project will use a similar approach: first, DL models will learn the type and origins of AT/AF from DTs(including patient MRI, image-based modelling and ECG data); the trained models will then be able to stratify patients and predict therapy from MRI/ECG data.

References

[1] Aslanidi OV, Colman MA, Stott J, et al. (2011).3D virtual human atria: A computational platform for studying clinical atrial fibrillation. Prog Biophys MolBiol107 (1), 156-168.

[2] Colman MA, Aslanidi OV, Stott J, et al. (2011). Correlation between P-wave morphology and origin of atrial focal tachycardia. IEEE Trans Biomed Eng. 58 (10), 2952-2255

.[3] Muffoletto M, Qureshi A, ..., Aslanidi O. (2021). Toward patient-specific prediction of ablation strategies for atrial fibrillation using deep learning. Front Physiol. 12, 674106.

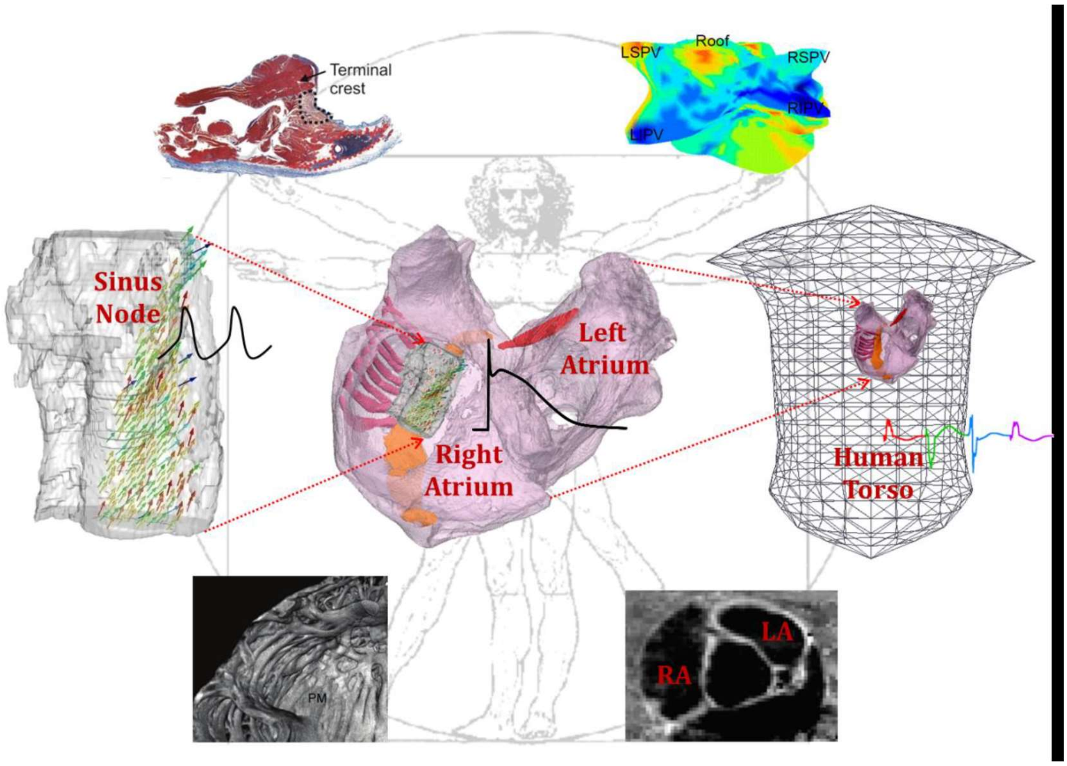

Illustration of Digital Twin of the atria and torso, which integrates multi-scale physiological knowledge and multi-modal patient imaging data, and links atrial excitations with ECG.