Personalized Ventricular Arrhythmia Simulation Framework to Study Vulnerable Trigger Locations on Top of Scar Substrate

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Personalized arrhythmia simulations have the potential to improve diagnosis and guide therapy. Here, we introduce a computational framework for personalized simulations of ventricular electrophysiology (EP) incorporating scar. This framework was utilized to study arrhythmia mechanisms in a patient who had a sudden cardiac arrest due to ventricular fibrillation (VF).

A simulation pipeline was developed from magnetic resonance imaging (MRI) to personalized EP simulations. From delayed enhancement MRI an anatomical model was constructed using a geometric model-based segmentation approach, where a generic model was deformed to the image. Regions of scar and border zone were segmented by image thresholding. Using these segmentations, a tetrahedral mesh was created using Cleaver2. EP was then simulated using the CARPentry monodomain solver. The Ten Tusscher ventricular EP model was adapted locally to reflect healthy, border zone or scar tissue. The clinically observed triggers were then replicated in the virtual model to study arrhythmia development. In this patient three distinct PVC origins were identified using electrocardiographic imaging (ECGI), one of which induced VF.

The simulated transmembrane voltage is shown in the figure below for a stimulation at the location that clinically induced VF as determined with ECGI. The figure shows voltage at t=320ms after the last pacing stimulus. Compared to a normal heart, i.e. no scar (panel A), the addition of scar and border zone introduces local repolarization heterogeneities (panel B), forming a potential substrate for re-entry. The repolarization abnormalities (arrows) clustered around the scar region. This virtual heart model was also triggered from the non-VF initiating locations to study different arrhythmic factors, e.g. coupling interval, border zone extent, etc.

Thus, this computational framework enables the identification of the mechanisms under which MRI-detected scar and PVCs can lead to arrhythmia in a personalized approach, validated through ECGI observations.