Reconstructing Cardiac Electrophysiology on a Left Atrial Geometry using Physics-Informed Neural Networks

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Personalized digital twin simulations of cardiac electrophysiology are increasingly in focus for treating atrial arrhythmias, yet hurdles include sparse clinical data for calibration and validation and simulation times that are infeasible for most clinics. Physics-Informed Neural Networks (PINNs) can provide a novel framework to integrate these sparse measurements with underlying biophysical laws with fast, clinically adoptable inference times. This study evaluates the ability of PINNs to reconstruct full-field action potential dynamics on physiologically realistic, anisotropic left atrial geometries.

We developed a PINN that reconstructs the spatiotemporal evolution of the cardiac action potential across a complex thin-shelled left atrial geometry under anisotropic conditions. Our method leverages surface gradient operators defined on a 2D manifold embedded in 3D space, enabling the network to enforce the Aliev-Panfilov model directly on the curved atrial surface. The network was trained on sparse in-silico voltage measurements using 500 supervised spatial locations from an atrial geometry generated by a statistical shape model.

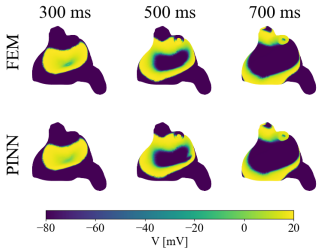

Figure 1: Predicted (bottom) and FEM-generated (top) transmembrane potential (V) at different time steps.

Our PINN accurately reconstructed cardiac action potential dynamics from sparse measurements across the entire left atrial surface (Figure 1). The network successfully captured spatiotemporal propagation patterns, activation sequences, and repolarization dynamics under anisotropic fiber orientation conditions with a mean relative L_2 error of 0.050.

This work demonstrates that PINNs can precisely recreate cardiac action potential dynamics from sparse in-silico voltage data over complex, curved manifolds representing physiologically realistic cardiac anatomies. The results represent a crucial step toward applying PINNs to patient-specific cardiac electrophysiology in the atria, enabling full spatiotemporal transmembrane voltage reconstruction from limited clinical measurements.