Parameterized Modeling of Ventricular Action Potentials for Forward ECG Simulations:

A Hybrid Approach Based on Resampled Biophysical Templates

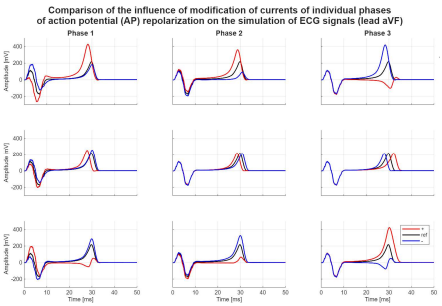
Kost Jan, Kinga Glądys, Elzbieta A. Pociask, Peter M. van Dam and Klaudia Proniewska

Center of Digital Medicine and Robotics, Jagiellonian University Medical College, Krakow, Poland
Laboratory of Functional and Virtual Medical 3D Imaging, Department of Diagnostic Imaging, University Hospital in Krakow, Krakow, Poland
AGH University of Science and Technology, Krakow, Poland

Simulation of the surface ECG using the Equivalent dipole layer model requires a representation of the transmembrane potential (TMP) throughout the cardiac cycle. While detailed ionic models, such as the ten Tusscher-Panfilov model (TTPm), offer high biophysical fidelity by simulating complex ionic conductances (I_{Kr}, I_{Ks}, I_{CaL}), their integration into large-scale forward and inverse problem simulations is computationally demanding and difficult to control for specific morphological variations.

We propose a parameterized TMP generator for the forward electrocardiography problem. Using TTPm-generated TMPs as "gold standard" templates, we created a library to adjust signal morphologies. To ensure direct control over the resulting ECG, TMP shapes were parameterized using three phase-specific electrophysiological features and integrated into an ECGSim-derived patient-specific volume conductor model via an EDL transfer matrix.

Adjusting these parameters reproduced diverse clinical ECG morphologies, allowing control over features like ST-segment length/elevation and T-wave amplitude. Modifying the TMP exclusively in Epicardium or Endocardium nodes yielded greater ECG signal differences than modifying the entire model (Global). For Phase 1 modifications, the correlation ranges were 0.71–0.94 (Epicardium) and 0.70–0.94 (Endocardium), compared to 0.89–0.97 for the Global model. Similarly, for Phase 3, the correlations were 0.58–0.84 (Epicardium) and 0.66–0.78 (Endocardium), versus 0.87–0.92 for the Global model.



Reproduced ECG morphologies.

Our approach bridges the gap between complex biophysical simulations and simplified analytical models. By distilling the TTP model into a few controllable parameters, this method provides a powerful tool for investigating how local changes in action potential morphology affect the global surface ECG. This is particularly valuable for sensitivity analyses in forward modeling and for the future development of more robust inverse problem algorithms.