From Clinic to Computation: Mapping Novel Electrophysiologic AF Metrics to Computational Models via Gaussian Process Emulation

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Introduction: Cardiac digital twins present a multiscale physics and physiology constrained framework for studying atrial fibrillation (AF). RENEWAL-AF identified novel indices of AF tissue level dynamics that correlate with AF recurrence, termination, and persistence. However, it is unclear how tissue properties may impact these measures, which is typically also computationally intensive to explore.

Methods: This pilot study addresses this using Gaussian Process Emulators (GPEs) to perform rapid parameter analysis. 60 simulations of AF (10x10cm 2D grids) using the Courtemanche model were analysed, focusing on ionic conductance (GNa, GK1) and tissue conductivities (longitudinal, transverse). Parameters were sampled using a Latin hypercube design. Using virtual catheters simulating the HD-grid catheter, we measured: i) correlation length (ξ); ii) rate of spiral wave formation (λ_f); iii) rate of spiral destruction (λ_d) - indicators of atrial electrical desynchrony. Simulated ξ, λ_f and λ_d values were used to train GPEs implemented through GPErks. GPE performance was assessed using R^2 and ISE scores and used for Global Sensitivity Analysis to quantify the importance of each model parameter.

Results: No significant difference was found between mean simulated values calculated in-silico using the virtual catheter (ξ=27.15 (95%CI:22.69,31.61), λ_f=3.81 (95%CI:3.38,4.24), λ_d=6.28 (95%CI:6.10,6.42)) and mean clinical HD-grid measurements (ξ=34.63 (95%CI:27.78,41.49), λ_f=3.67 (95%CI:2.61,4.72), λ_d=6.54 (95%CI:5.41,8.61)) (all P>0.05). For ξ, GPEs returned an R^2=0.60, compared to 0.45 for λ_f and 0.41 for λ_d, and took >2 mins to run. Uncertainty analysis demonstrated ISE scores of 21.06 for ξ, 21.39 for λ_f and 17.70 for λ_d. Sobol variance identified longitudinal tissue conductivity as most influential on ξ, which was also observed in addition to GK1 for λ_f and λ_d.

Conclusion: Despite scope to optimise and improve GPE performance further, this pilot demonstrates GPEs' potential to efficiently map bespoke tissue scale AF metrics to model parameters, potentially further supporting cardiac digital twins for clinical/research use.